HYDRODYNAMIC ANALYSIS OF SPAR PLATFORM SUBJECTED TO PM SPECTRUM WAVE

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by

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CERTIFICATION OF APPROVAL

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Civil Engineering Programme
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Approved:

Prof. Dr Kurian V. John
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

Jun 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Nur Dalila Binti Alias

ABSTRACT

The thesis presented a hydrodynamic analysis of a spar platform subjected to PM Spectrum wave. Holstein truss spar platform owned by Shell and BP has been selected for the study. It is located at Gulf of Mexico, 150 miles south to New Orleans. The study focused mainly on hydrodynamic analysis of wave forces acting on the structure and its motion responses at hard tank subjected to field environmental condition. This research emphasizes on the fundamentals of the structure behavior of the truss spar platform. It is an initiative taken by UTP to help improving the understanding of deepwater floaters due to recent deepwater field discovery in Malaysian waters such as KIKEH and Gemusut Kakap. It is expected to improve UTP graduates thus reducing the dependency on foreign consultant which eventually lead to cost reduction. The spar is modeled as a rigid cylinder with 3-degree of freedom (surge, heave and pitch). It is assumed to be anchored on the sea floor by mooring system. A set of regular and random wave condition have been considered in this research. Calculation of the incoming wave was done using Airy's linear wave theory while Morison Equation was adopted to compute the wave forces. The frequency domain analysis subjected to PM spectrum wave was done in order to model the distribution of energy density of the sea of the Holstein field. Based on the wave spectrum, motion responses for each direction were calculated using RAO Equation. The motion responses profile evaluations were carried out based on the extreme condition occurs once in 100 years. It is discovered that for regular condition, surge having maximum response up to 0.62 m, heave 0.18 m and pitch 0.068 radians occurs at a frequency of 0.0055 Hz. As for random conditions, maximum surge, heave and pitch value are 2.5 m, 0.5 m and 0.03 radians respectively.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

As the Oil and Gas industry is expanding, the demand on the deep water exploration has been increasing and new technologies need to be developed to sustain the need of the industries. Many innovative deepwater structures have been developed and modified in order to reduce cost. Wang Yin et al. (2008) recite that spar platform are one of the promising inventions for floating offshore structure since they offer economical and reliable solution for oil production in deep and ultra-deep water. This is due to its excellent heave motion characteristic. However, spar concept is not a new offshore technology. A.K Agarwal et al. (2003) mentioned that spar concept has been used since 1961 in various offshore activities such as research vessels, communication relay stations, storage and offloading platform until in 1996. The first production spar platform had been installed in Gulf of Mexico namely Oryx Neptune SPAR. Since then, sixteen more spar platforms have been operating which are two Classic spars, thirteen Truss spars and one Cell spar located mainly in Gulf of Mexico except for Kikeh Truss Spar which is located in Malaysia.

Spar platform consists of four major systems which are hull, moorings, topsides and risers. It is supported by a mooring system to maintain its position. Each type of spar reflects different range of functionality and operating environment. Zhang Fan et al. (2007) stated that the unique feature of a Classic spar is its deep-draft hull, which produces a low motion characteristics compare to other floating structures. 90 % of its structure is located in the water thus enhancing the stability of the structure. Wave action at the surface is dampened by the counter balance effect of the structure weight even in an extreme sea condition. Low motions and protected centerwell also provide excellent configuration for deepwater operations. However, this type of spar has a disadvantage when come to a sea with ambient deep current where drag force will be significant for a large cylindrical shape. This is where Truss spar becomes an attractive solution. It is a modification of a Classic spar where the lower section of the caisson hull being replaced by a truss, separating the top hard tank and bottom soft tank. The horizontal steel plates contributed to lower heave motion by increasing the added mass and damping for the structure. It contributes to lower drag forces compared to Classic spar type and reduce the mooring loads applied to the structure. Heave response to truss spar can be manipulated by varying the plate characteristics tuned to the structure to produce desirable maximum heave response. Spar can be affected by strong currents where a spiral strakes might be used to suppress vortex induced vibration. However due to short buoyancy cylindrical section for truss spar, the effect is reduced if compare to classic spar. The purpose of this study is to understand the behavior of the spar responses in relation with hydrodynamic analysis of the selected field.

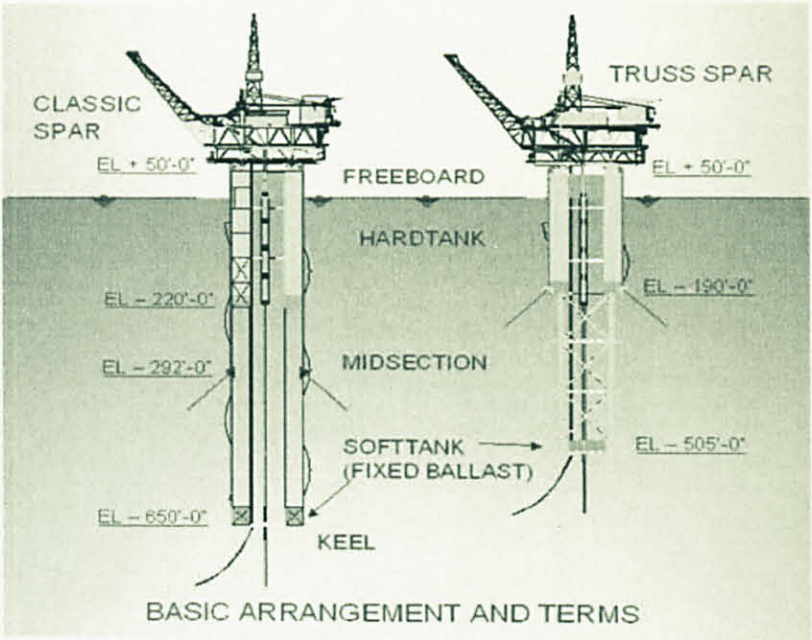

Figure 1.1: Basic arrangement between classic and truss spar

1.2 PROBLEM STATEMENT

Since the first Malaysian deep water structure, SPAR platform was installed at Kikeh field in 2007, tremendous studies have been done to understand the structure behavior and its responses to the environmental loadings. Studies on deepwater offshore structure are considered a crucial movement in Oil and Gas industry. This is due to development of deepwater field such as in Kikeh and Gemusut Kakap field. Offshore related engineers and technologist are required to equip themselves with knowledge to understand the deepwater technologies in order to assess and maintain the structure in the future. Lack of expertise in the field is considered as a short coming and creates a need to consult with foreign consultant which will result to major expenditure. Thus, it is crucial to have more experts in deep water technologies in Malaysia. A deep and continues research need to be established in order to fulfill the demand of the industry and thus create an archive of researches in deep water offshore technologies. By doing this research, it will give benefits to the related companies in the industry in understanding more on the deep water structure behavior. This will then reduce the dependency toward the foreign consultancy. It is an aim that this practice will continue and will help to increase the number of experts in offshore industry in the future.

1.3 OBJECTIVES

At the end of the study, several objectives that expected to achieve are:

- To complete a dynamic analysis of spar platform due to PM Spectrum wave.
- To determine motion responses of surge, heave and pitch for the selected spar platform and
- To complete an experimental study on a scale model behavior in the offshore lab.

1.4 PROJECT SCOPE AND OVERVIEW

For the purpose of this study, the author focused on the Truss spar platform. This included hydrodynamic analysis of wave and current loading calculation on the hard tank of the structure related to the metocean data of the field under PM Spectrum wave. Selection of the field are based on the complete design data of the Spar platform and known environment condition of the field. It is to ensure that all the selected data discussed in this paper is relevant to the current situation in the industry. The study also aims to benefit the operator companies for developing a fundamentals understanding as well as addressing any matters in designs and maintenance.

For numerical simulation, focus is given on the evaluation of regular and random wave condition. This study emphasized on frequency-domain approached. This technique is used mainly for linearization equation of motion, which will be assumed in this study. Apart from that, Morison equation is employed to calculate the wave forces acting on the structure. RAO equation is analyzed through out the study in order to obtain surge, heave and pitch responses and wave profile. Microsoft Excel will be used in this study as an assistant for calculation and analysis purpose.

An experiment was conducted at the end of the study to see the behavior of the model due to the extreme environment condition. The reason for experiment study is to observe and compare experimental and theoretical responses subjected to motion. The model used in this experiment was borrowed from one of the author's colleagues and the experiment was done in collaboration form.

As a whole, the project is a success and was completed on time since there is no significant obstruction while carrying out the project. It is aimed to capture the essence of the truss spar characteristic by emphasizing the fundamental of a truss spar behavior due to the wave and current loading and the sea condition. The study is also aiming to strengthen the Oil and Gas industry in Malaysia.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Spar structure is not a new concept to the offshore industry. It has been developed since 1960's. Spar platform buoy type has been built before such as floating instrument platform (FLIP) used as oceanographic data gathering and Brent Spar platform as oil storage and offloading platform. Later development in deepwater structure has introduced spar as a platform used for drilling, production and both. Major systems implemented in a spar platform are hull, moorings, topsides and risers. It is modeled as a rigid body with six degrees of freedom, connected to a sea bed by multi component of catenaries mooring lines which are attach to a spar platform at the fairleads. Researches have conducted broad scope of studies in various aspect of analysis in order to enhance the understanding in the spar effectiveness. Most of the analysis covers dynamic analysis on the main structure, motion responses, coupled dynamic analysis, moorings line and so on. Numerical analysis and experiments also has been conducted using various methods and equations to explore every possibilities and outcomes which can contribute to the industry.

2.2 STUDIES ON RESPONSES

Sadeghi et al. (2004) completed a study on responses analysis of a truss spar wave due to loading in frequency domain by using a simplified technique. A novel method using tensor properties of the added mass coefficient was developed in this study. A transformation law for a second order was found using a non zero added mass coefficient and also the repeated application of the parallel-axes theorem. The force decomposition of the Morison Equation was use to add viscous to the linear equation of motion. From this study, it is shown that the nonlinear equation of motion can be solved without iteration, which is contrary to the conventional method. In case of heave motion, this technique delivered more accurate results compared to the conventional methods in time domain.

Agarwal and Jain (2002) contributed in solving a dynamic behavior of a moored Spar Platform as an integrated system by modeling a spar platform as a rigid cylinder with six degrees-of-freedom at its center of gravity (COG). The iterative incremental Newark is used in order to analyze the responses in time-domain. The report stated that "it is assumed that the mooring line is close to its keel and the spar is connected to the sea bed by four multi component catenaries mooring lines, placed perpendicular to each other which are attach to the spar platform fairleads. The dynamic analysis of the structure involves formulation of non linear stiffness matrix with considerations of fluctuations in mooring line system due to the variables buoyancy and other nonlinearities." From the studies conducted, it is found out that the force-excursion relation of a single mooring line depends mainly on the initial horizontal force at the top of the mooring line due to the nonlinear behavior of the cable force.

Fan. J et al. have come out with a study on the influence of heave motion on the damping force of a mooring line. He presented with some investigations on the characteristics between the heave motions and damping force of mooring lines. The study was conducted using time domain approach with different upper end motions in order to calculate variations of dissipated energy of mooring line damping force. A significant effect from wave frequency heave motion on the damping of the mooring line was discovered on the low frequency surge motion. Increase of amplitude and frequency of the heave motions contribute to the increment of damping in mooring lines.

2.3 PARAMETRIC RESEARCH

B. J. Koo et al. (2004) ca me up with a complete study on the mathieu instability for a spar platform. This study was conducted to address the problem when there is a harmonic variation in the pitch restoring coefficients caused by large heave motion and the period of the heave motion. "The pitch restoring coefficient was represented by a function of the displaced volume and the metacentric height of spar hull. Due to heave motion, the displaced volume and the metacentric height of the spar platform change in time and this heave/pitch coupling can be represented by Mathieu's equation. This study was done to evaluate damping effects and hull/mooring/riser coupled effects on the principal instability. Heave/pitch coupling of the spar platform was simulated and was considered using the modified Mathieu equation. The wave elevation effect on Mathieu instability is also investigated. The Mathieu instability of a practical spar platform is carefully checked by a series of systematic simulations and comparisons of many different scenarios. The available damping is found to be important in suppressing the instability." The results also show that the additional pitch restoring force from buoyancy-cans plays an important role in the spar Mathieu instability.

Y. Bai et al. has done an extensive study on steel catenary riser fatigue due to vortex induced spar motions. "Impact of Vortex Induced Motions (VIM) of a Spar on riser design was address in this paper. The sensitivity analysis also has been carried out to evaluate the soil stiffness, flex-joint stiffness, design pressure and hang-off angle. In one of the examples of fatigue analyses presented in this paper, while combining fatigue damages from VIV, wave induced fatigue and installation fatigue, the riser system met the required criterion of 200 years. It is also concluded that currents applied out-of-plane to riser generate higher fatigue damage than currents applied in plane to the SCR. Moreover, VIM fatigue life is observed to be sensitive to the hang-off angles.

2.4 NUMERICAL AND EXPERIMENTAL STUDIES

Wang et al. (2007) explains on the studied conducted for geometric spar for analyzing of hydrodynamic parameter with consideration of coupling effect on the vessels and risers by using frequency- and time- domain. They modeled the hydrodynamic vessel in three dimensions (3-D) together with mooring system and risers thus carried out numerical simulation of its wave loading and motion responses in specific wave condition by using a program called SESAM. This method successfully done and shows results of no independency of heave motion with incident wave angle, symmetrical characteristic between incident wave and pitch and rolls as well as surge and sway, and also behavior of yaw motions which is close to zero at any incident wave angle. Apart from that, it is found in the frequency-domain analysis that existing of a heave plate induced deductions of heave motion of RAO both in low frequency range and wave frequency range.

A numerical analysis has been conducted by Zhang et al. (2007) in order to evaluate hydrodynamic performances of a new spar concept where they used numerical simulation approach in analyzing both operating and survival condition of the spar. The new spar concept was taken from the truss and cell spar features and named it as Cell-Truss spar. It was aimed to take advantage on the heave plate damping of the truss to obtain satisfactory heave motion performance while reducing construction and installation procedure difficulties by implying the cell spar concept. Coupled approach has been taken into consideration by transferring the total loads (dynamic included) from the "slender body models" of mooring lines and risers into the "large body model" of a floater. The presentation of dynamic behavior of the coupled vessel/slender structures system was done by acquiring irregular wave frequency (WF) and Low Frequency (LF) environmental loading. They combine all the system components and describe it in FEM-model. It was found that the motion responses of the new spar concept, especially in heave is adequately low to satisfy the installation of the rigid.

An experimental investigation of motion control devices has been conducted by M.J Downie et al. (2000) to gain an understanding of the truss spar behavior and investigate the factors affecting the motions using plates of various types across their bays. It is discover that large plates provide more damping than the small one as well as solid plates to perforated plates. Small perforated plates with small filling holes enhances its damping by 52 %, additional of perforated edge increase by 72% and filling the holes of the small perforated plate and adding a solid edge increase the damping to 94%. From RAO point of view, the spar behaves similarly in surge and pitch in regular wave. Nevertheless, significant difference can be observed in heave response where large plates give smaller response to compare with small plates. Similarly, the solid plates are associated with small responses than the perforated one. All of the finding points that the most important factor is the type of plate on the overall added mass. It also showed that plates extending beyond the platform of the bays significantly improved the behavior of the spar. This has the beneficial effect both on added mass and damping the latter being due perhaps to enhanced flow separation and vortex shedding from the plate edges.

2.5 WAVE KINEMATICS

Ocean waves are random and irregular in shape, height, length and speed of propagation. A regular travelling wave is propagating with permanent form. It has a distinct wave length, wave period, wave height. It has the characteristics of having a period such that each cycle has exactly the same form. Thus the theory describes the properties of one cycle of the regular waves and these properties are invariant from cycle to cycle. Figure 2.1 illustrate the regular waves form and its properties.

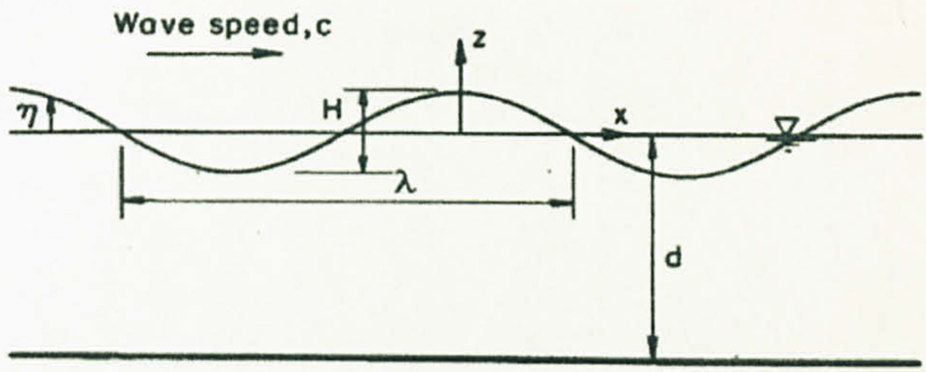

Figure 2.1: Regular wave properties

Wave length: The wave length L is the distance between successive crests.

Wave period: The wave period T is the time interval between successive crests passing a particular point.

Wave frequency is the inverse of wave period: $f = 1/T$.

Wave angular frequency: $\omega = 2\pi/T$.

Wave number: $k = 2\pi/L$.

In irregular or random waves, the free surface elevation h (x,y,t) is a random process. The local wavelength of irregular waves can be defined as the distance between two consecutive zero up-crossings as shown in Figure 2.2.The wave crest in irregular waves can be defined as the global maximum between a positive up-crossing through the mean elevation, and the following down-crossing through the same level. Random waves can be modeled as a summation of sinusoidal wave components where will be explained in detail in Chapter 3.

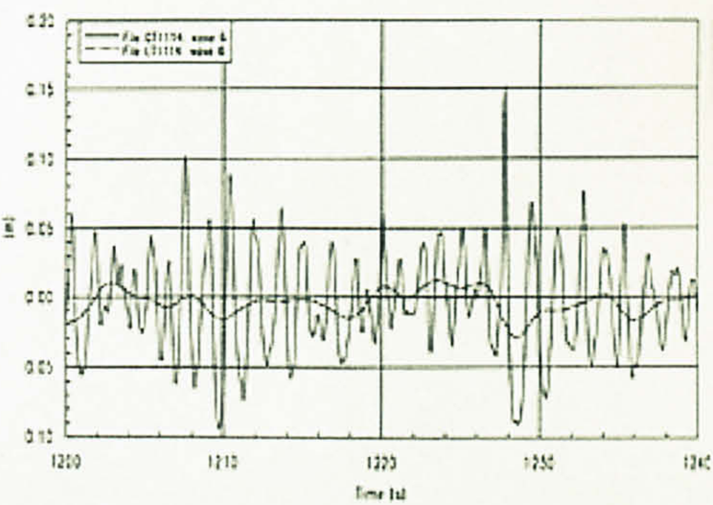

Figure 2.2: Irregular wave trend

The most crucial value that needs to be calculated in order to complete a hydrodynamic analysis of a structure is the wave forces. The wave force developed on the structure is due to the water particles motion in the sea which causes some forces due to the velocities and acceleration of the particles motion. The forces give a significant impact to the structure thus important for designing .Some of the conditions for using this equation are;

• Cross-sectional dimensions adequately small to allow the gradients of fluid particle velocities and accelerations in the direction normal to the member to be ignored

• L> 5 D, where L is the wave length and D is the diameter or other projected cross-sectional dimension of the member.

2.6 SPECTRUM MODEL

For regular wave, a single wave method is employed which is commonly done in design stage. It can represent the extreme wave by using an appropriate wave height and period in order to determine the extreme response of the structure. For random wave, an energy density spectrum was applied to describe the energy content of the ocean wave and its distribution over a frequency range of the random wave which is an important analysis to be conducted for designing a floating structure. Some of the important parameters used for random waves are shown in Table 2.1

PM Spectrum model is a commonly used model to evaluate the total energy content of the storm as well as the frequency distribution. It is a one-parameter spectrum model which was written in peak frequency coo. The highest peak of the graph indicates the maximum energy density obtained by the spectrum at one particular frequency, where it can gives an indication of the sea condition as illustrated in Figure 2.3.

Table 2.1: Common statistical random wave parameters

Parameter	Symbol	Description
Short-term record length	T_s	Duration of the storm
Significant wave height	H_s	Average height of the highest one third waves in a short-term record
RMS wave height	H_{rms}	Root mean square value of the individual wave heights in a short-term record
Peak frequency	ω_0	Frequency at which the spectrum peaks.
Significant wave frequency	ω_s	Average frequency corresponding to the significant waves in the short-term record
Mean frequency	$\overline{\omega}$	Mean frequency of the individual waves in a short-term record
Wave standard deviation	σ	Standard deviation of the wave time history in the record

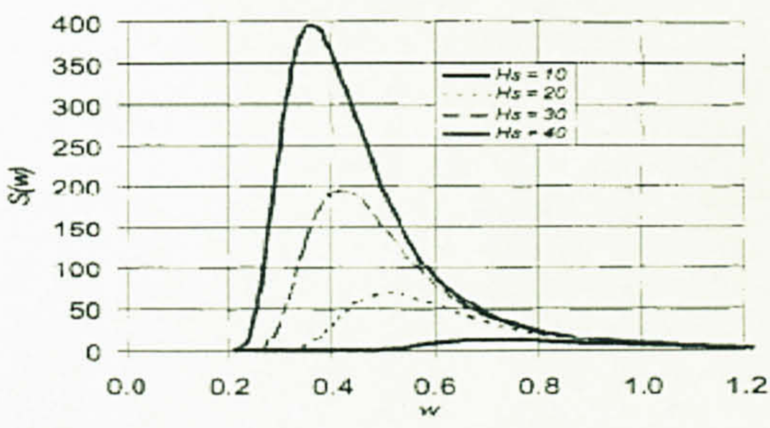

Figure 2.3: Fully developed P-M Spectrum for different seas

2.7 DYNAMIC ANALYSIS OF THE SPAR

An offshore structure is always considered to be in motion due to the wave forces. Few methods have been applied in order to assess responses of floating structures in all direction as shown in Figure 2.4. The most commonly used methods are frequency domain and time domain analysis in Frequency domain analysis is much simpler and faster method to be employed as being cited by Sadeghi et al. (2004). However, this method is subjected to error and inaccuracy due to linearization of the non-linear system assumed in the analysis, which made the time domain more preferable by the researchers. B.S Wong (2008) explained that frequency domain analysis is being employed broadly in designing phase in order to predict long term responses. The responses which were computed through spectral formulation can make estimation from the input random wave.

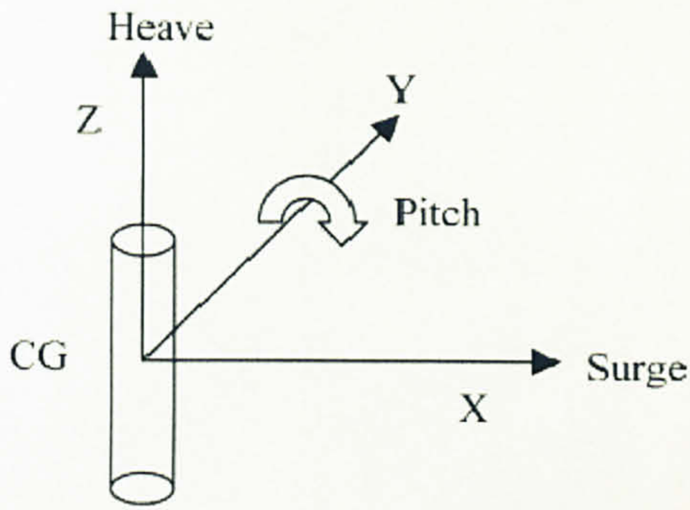

Figure 2.4: Responses of the floaters in all direction.

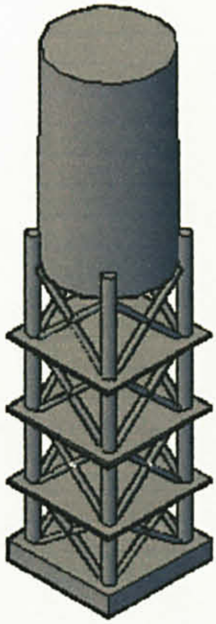

Figure 3.1: An AutoCAD model of Holstein Truss Spar hull

3.2 STRUCTURAL MODEL

The spar is modeled as a rigid cylinder with 3 degrees-of-freedom (surge, heave and pitch) along X, Y and Z axes at its CG. Calculation will be focused on hard tank structure without consideration of truss, soft tank and mooring system of the spar platform. The details of the design data and environment condition will be elaborate in Table 3.1 below. Here, mooring lines attach near to CG provide low dynamic positioning thus gives stability and stiffness to the spar platform. Some of the assumptions that going to be include in this research are;

1. The platform is considered as a rigid body having 3 degrees-of-freedom.
2. The truss spar is anchored to the sea floor by mooring system.
3. Pretension in mooring lines is neglected.
4. Wave forces are estimated at the instantaneous equilibrium position of the Spar platform. The wave diffraction effect is neglected.
5. Platform has been considered symmetrical along surge axis. Directionality of wave approach to the structure has been ignored in the analysis and only uni-directional wave train is considered.

Table3.1: Design Parameter and wave data of Holstein Truss Spar Platform

Hull Dimensions	
Draft (m)	211
Hull Length (m)	227
Hard Tank Diameter (m)	46
Hard Tank Length (m)	89
Total Truss Length (m)	131
Keel Tank Length (m)	8
No of Heave Plate	3
Weight	
Hull Displacement (MT)	105000
Vertical CG (m, below MWL)	65
Normal Total Weight (MT)	125000
Vertical CB (m, below MWL)	59
Metocean Data Due to Extreme Condition	
Water Depth (m)	1324
Maximum Wave Height, Hmax (m)	24
Significant Wave Height, Hs (m)	12.9
Associated Zero Wave Period, Tass (m)	16.7
Significant Peak Wave Period, Tp (s)	14.25
Water Density, ρ (Kg/m^3)	1030
Drag Coefficient (C_d)	0.6
Inertia Coefficient (C_m)	2.0

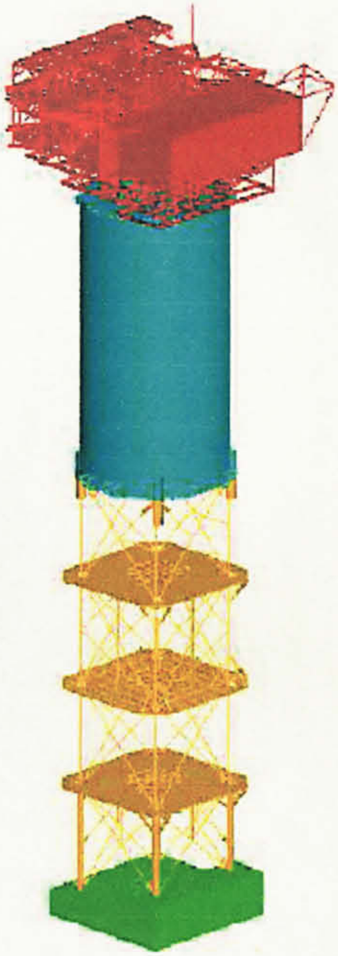

Figure 3.2: Holstein structural model

CHAPTER 3

METHODOLOGY

3.1 GENERAL

A Gantt chart was constructed based on the key milestone given by the co-coordinator where the author manages to arrange a sequence of steps taken in order to complete this study which can be view in Appendix A.

Paper studies has been done based on the journals and offshore websites to select the best spar platform geometry and environment condition. From researched conducted, the author has selected Holstein Truss spar platform as the reference spar. All of the calculation and analysis was conducted in Excel spreadsheet software.

A.S Jesudasen et al. (2004) presented in his paper that Holstein is the largest ever built spar platform . The length of the spar is 227 m and diameter of 46 m, having 1324 m of water depth. It is a truss type spar, with a large cylindrical buoyant hard tank penetrating the sea surface and truss opening structure terminating at the vessel keel with smaller buoyant soft tank. S. Perryman et al. (2005) explain that this spar was designed with a hull displacement of 105 000t due to the requirement of production, drilling and export of the field, which characterized Holstein spar as the largest ever built spar platform. The Holstein field is located in an area of Gulf of Mexico. It is known to be predominated by loop and eddy current generated by Gulf Stream. These currents has resulted to the largest mooring system ever installed to a spar, the heaviest and longest suction piles as well as considerable challenges over hull Vortex Induced Motion (VIM) and Vortex Induced Vibration (VIV). Figure 3.1 display the rough dimension for Holstein Truss spar modeled using AutoCAD software.

3.3 WAVE FORCES

A set of calculation was established to conduct theoretical dynamic analysis acted on the structure. All direction of wave forces acted on the structure such as Fx, Fy and Mz also can be analyzed.

For this field, an extreme condition happening once in 100 years is taken as the environment condition. Due to this, calculation was done by dividing the hard tank into smaller compartment in order to determine the maximum force applied. For the purpose of calculation, the wave is assumed to be unidirectional and directed in X direction. The author applied Morison Equation to calculate the forces acting on the structure. The formula of Morison Equation is as stated below;

$$\mathbf{F} = \mathbf{F}_I + \mathbf{F}_D \tag{1}$$

$$F = C_M \frac{\rho\pi D^2}{4} u' + C_D \frac{\rho D}{2} |u|u \tag{2}$$

where the force (F) is the wave force per unit length on a circular cylinder; u and |u|, water particles velocity normal to the cylinder, ρ for sea water density and C_m and C_d which contribute to inertia and drag coefficient of the structure respectively. All of the component will give the desired total wave force (F) in calculated direction.

From Airy's wave theory, the corresponding horizontal and vertical components of wave particle velocity and acceleration at a particular location can be calculated, given the wave height and wave period. Equations that can be used to determine the wave water kinematics are:

Horizontal Water Particle Velocity, $$u = \frac{\pi H}{T} \frac{\cosh ks}{\sinh kd} \cos\theta \tag{3}$$

Vertical Water Particle Velocity, $$v = \frac{\pi H}{T} \frac{\sinh ks}{\sinh kd} \sin\theta \tag{4}$$

Horizontal Water Particle acceleration, $$u' = \frac{2\pi^2 H}{T^2}\frac{\cosh ks}{\sinh kd}\sin\theta \qquad (5)$$

Vertical Water Particle acceleration, $$v' = \frac{2\pi^2 H}{T^2}\frac{\sinh ks}{\sinh kd}\cos\theta \qquad (6)$$

where, s= y+d ; θ= kx-ωt ; k, wave number (2π/L); ω, natural frequency (2π/T); T, wave period; y, height of the chosen point of water particle kinematics; x, chosen point of water particle kinematics from the origin in horizontal direction; t, time at which the water particle is evaluated; L, wave length; H, wave height; and d, water depth.

3.4 FREQUENCY DOMAIN ANALYSIS

Frequency domain analysis is a term used to describe analysis of mathematical function, in this case, the wave height with respect to frequency. This analysis is a compulsory to observe the distribution of wave energy with frequency and direction of the spar platform. At this stage, total energy of the ocean wave can be presented. Once analysis has performed, motion response for surge, heave and pitch of the spar will be calculated based on the wave spectrum. As a final point, the motion response profile will be generated from motion,response spectrum which has been determined earlier on.

3.4.1 WAVE SPECTRUM

Energy density of the wave will be analyzed using P-M spectrum wave with frequency domain analysis method. This analysis will involve equations of P-M spectrum in term of frequency cyclic (ω/2π) as written below;

$$s(f) = \frac{\alpha g^2}{2\pi^4} f^{-5} exp\left[-1.25\left(\frac{f}{f_0}\right)^{-4}\right] \qquad (7)$$

where α = 0.0081 and peak frequency , f_o = $\omega_o/2\pi$. Relationship between peak frequency and significant wave height can be shown in equation below;

$$\omega_o = 0.161g/\,H_s \qquad (8)$$

Each frequency (f_i) is related to its own wave spectrum density (S_f). This will be used in obtaining wave height (H_f) for one frequency by using equation;

$$H(f_1) = 2\sqrt{2\,H(f_1)\Delta f} \tag{9}$$

Time history of the wave profile can be obtained from;

$$\eta(x,t) = \sum_{n=1}^{N} \frac{H(n)}{2} cos\,[k(n)x - 2\eta f n(t) + \varepsilon(n)] \tag{10}$$

where, x, horizontal direction of evaluated wave profile location from the origin; t, the time instant at which wave profile was evaluated and was incremented; wave number k(n); wave length L(n) corresponded to the wave length for nth frequency f(n); wave height H(n) was computed from Equation (9) for nth frequency; and the n was the total number of frequency band of width Δf, dividing the total energy density.

3.4.2 MOTIONS RESPONSES

For this study, the author assumed the truss spar to be anchored to the sea floor by mooring lines. This system will give impact to the motion of the spar. The anchored system will be in tensioned thus results in the motion responses of the structure in surge, heave and pitch. Motion responses of the structure mainly surge, heave and pitch will be calculated by using RAO's Equation as stated below;

$$\frac{F_I / (\frac{H_{max}}{2})}{(K - m\omega^2)^2 + (C\omega^2)^{1/2}} \tag{11}$$

RAO is an amplitude of response per unit wave amplitude; FI as inertia force; K as stiffness of the structure associated with different type of motion; m as summation of mass and added mass of the structure associated with different type of motion; C as structural damping ratio; H as max wave height; and ω as natural frequency corresponding to particular frequency. Below are the explanations on Equation used to obtain each value for Equation 11.

Using Morison Equation (Equation 2), total force (F,,) for surge in X axis and total moment (M_Z) for pitch motion about Z axis (with respect to COG) were calculated based on the wave height, H extracted from Equation 9 and wave period, T which corresponded to the frequency range from 0.005 Hz to 0.4 Hz. Force in Y axis (FY) which is heave motion were computed using Equations below;

Force in Y-axis, $$Fy = p \, x \, A \quad (12)$$

Dynamic Pressure, $$p = \rho g\left(\frac{H}{2}\frac{\cosh ks}{\cosh kd}\cos\theta\right) \quad (13)$$

where s= y+d, k, wave number (2π/L), d, water depth, A, cross section area of hard tank, Θ, angle of inclination at the fairlead point and p, seawater density. Total mass (m) for surge, heave and pitch motion were calculated using equations stated below;

Total Mass for Surge, $$m_{11} = (m + m_{a11} \quad (14)$$

Added Mass in Surge Motion, $$m_{a11} = (A \times Draft \times p) \quad (15)$$

Total Mass for Heave, $$m_{22} = (m + m_{a22}) \quad (16)$$

Added Mass in Heave Motion, $$m_{a22} = \frac{\rho \pi D^3}{12} \quad (17)$$

Total Mass for Pitch, $$m_{33} = (MI + MIa) \quad (18)$$

Mass and Added Mass of Inertia for Pitch, $$MI = m_{11} \times \left(\frac{3}{4} D\right)^2 \quad (19)$$

Once total mass for all motions is obtained, natural frequency, ω_N which was taken from natural period, T_N obtained from other studies conducted for Gulf of Mexico condition was used in computing stiffness value, K of the spar. Stiffness Equation used in obtaining surge, heave and pitch motion is;

$$K = \omega_N^2 \times m \quad (20)$$

$$\omega_N = \frac{2\pi}{T_N} \quad (21)$$

3.4.3 MOTION RESPONSE SPECTRUM

To generate a motion response spectrum, wave energy spectrum (equation 7) can be multiplied with the square of RAO. The formula of motion response spectrum can be written in two forms, which are;

$$S_x(f) = [RAO\ (\omega)]^2\ S(f) \tag{22}$$

$$S_x(f) = \left[\frac{\frac{F_I}{\left(\frac{H}{2}\right)}}{\left[(K-m\omega^2)^2 + (C\omega^2)\right]^{\frac{1}{2}}}\right]^2 S(f) \tag{23}$$

where RAO equation is taken from Equation 11 and $S_{(f)}$ is the energy density of the sea with respect to frequency which was calculated using PM Spectrum wave earlier.

3.4.4 MOTION RESPONSE PROFILE

Generation of motion response profile is completed by using equation 10 as stated previously. Motion response spectrum is essential for this purpose where from the spectrum, the expected response (time-series) in a given interval time (500 seconds) can be deduced.

3.5 EXPERIMENTAL SETUP

An experiment was performed at the end stage of the analysis to demonstrate the behavior of the structure according to the field condition which will be set in the Offshore Lab, UTP. This is to establish the connection between calculation analysis and reaction of the structure wheret the graph obtained from the lab result trend is compared with the theoretical result.

The experiment was done in collaboration with one of the author's colleague who was doing experimental analysis on the behavior of Truss Spar Platform. For the experimental setup, 10 fishing line, each tied to an anchor was fixed at the keel of the prototype to stabilize the spar from moving, where it will represent the mooring line at the field. Once the spar is confirmedly steady, a set of random wave using PM Spectrum Wave condition generated by the wave paddle was applied to the structure. The experiment was conducted in two condition, optimum and extreme condition which are referred as condition 1 and 2. This is to evaluate the behavior of the prototype in both conditions. Condition 1 comprise of 0.03 m wave height and wave period of 0.5 seconds while condition 2 had 0.05 m of wave height and 0.5 seconds as wave period.

The behavior of the structure was recorded using video recorder in order to establish wave profiles of surge, heave and pitch obtained from the experiment. Only condition 2 behavior was plotted to compare since the theoretical was done by using 100 years extreme condition. Once the wave profile is obtained, a comparison of behavior between theoretical and experimental will be done for each of the responses.

CHAPTER 4

NUMERICAL RESULTS AND DISCUSSION

4.1 WAVE FORCES AND MOMENT

Wave forces acting at X direction on different part of hard tank is calculated by using the Morison's Equation and is summarize in Table 4.1 below. The wave force was assumed to act on the origin of the spar which is x= 0 m and varies the time from 0 s to its associated wave period, T_{ass}= 16.7 s. From the calculation, maximum summation of the forces acting on the hard tank with respect to time is determined, which is 262 000 KN at time 12.7 s. In the calculation, only the forces acting on the hard tank is calculated without considering the truss part. This is due to the observation from previous paper indicates the insignificant wave force experienced by the truss and soft tank section. Detailed calculation of wave force and moment can be referred at Appendix B and C respectively.

Table 4.1: Wave Forces and Moment distribution on Truss Spar

Sections	**Hard Tank**
Fx (MN)	262
Fy(MN)	86.02
Mx (MN.M)	9244.3

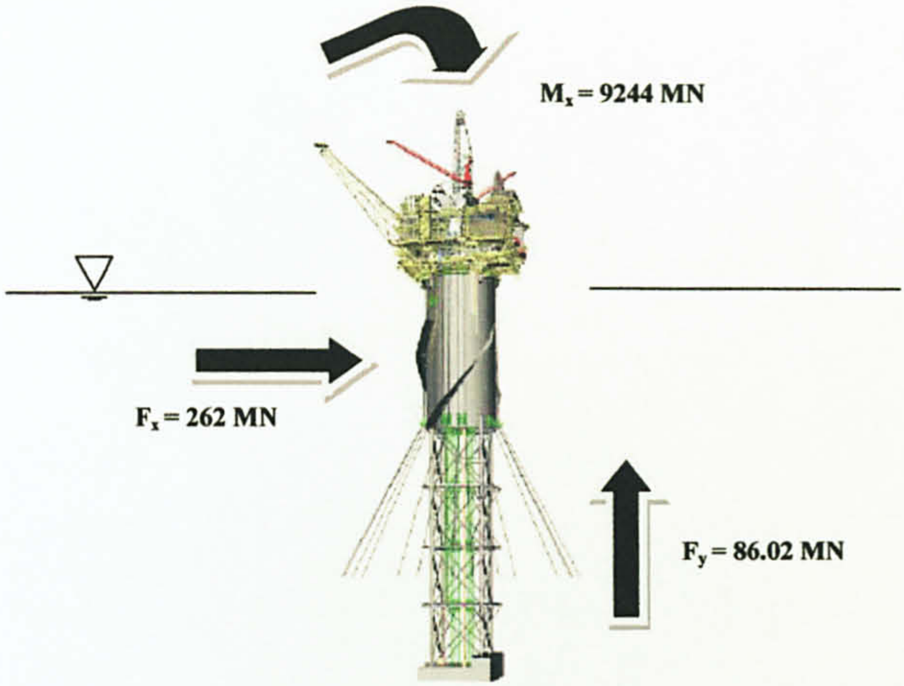

Figure 4.1: Holstein Spar with forces acting on the hard tank

From table 4.1, it is shown that due to large forces exerted on the hard tank, large moment (in clockwise direction) was produced. The direction of moment was controlled by wave forces acting on the hard tank and location of CG on the truss spar. Figure 4.1 is a summary of wave forces direction in each considered axes.

4.2 P-M WAVE SPECTRUM

Pierson-Moskowitz (PM) spectrum is an empirical relationship that defines the distribution of energy within the ocean by using Equation 7.The PM spectrum wave having range from the frequency of 0.005 Hz to 0.40 Hz with incremental of 0.01 Hz of frequency as shown in Figure 4.2. A wave profile is then generated for a time ranging from 0 sec to 500 sec using Equation 10 and calculated wave height. This profile was captured when the wave acted on the truss spar at X= 0 m (original position). A random phase in the range of 0 to 2π is computed using Random number generator, R_N to retain the randomness of the time history. Figure 4.3 below illustrate the wave profile generated from the previous equation.

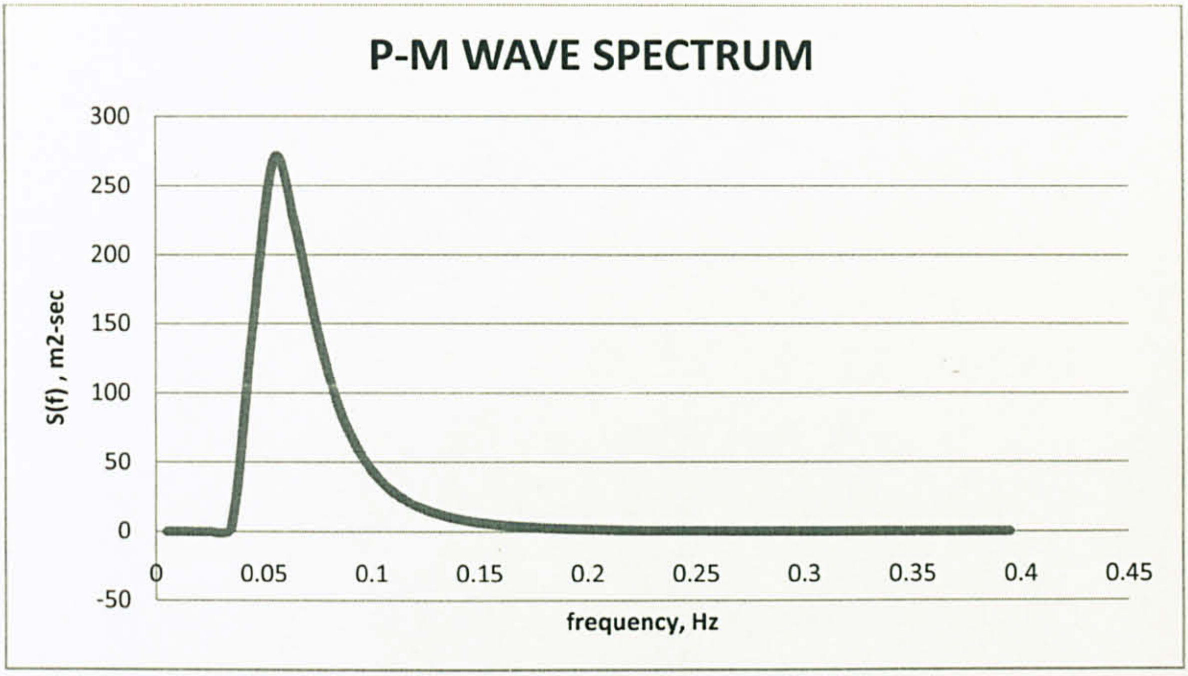

Figure 4.2: P-M spectrum for H_s = 12.9 m

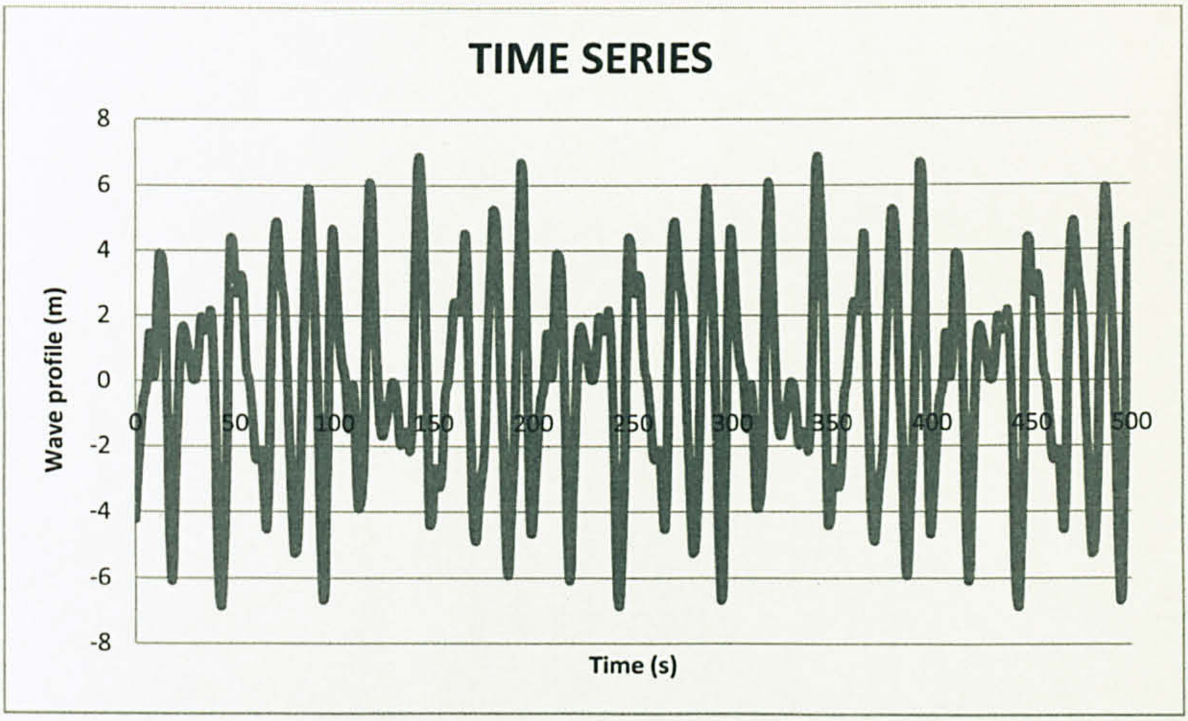

Figure 4.3: Generated wave profile

Based on the Figure 4.2, the wave energy at frequency of 0.055 Hz was the highest. Generated wave profile from Figure 4.3 indicates that Holstein truss spar platform can have the highest wave height of 6.3 m. Appendix D will give the detail calculation of the wave spectrum and wave profile respectively.

4.3 MOTION RESPONSES

For a free to move structure in the ocean subjected to regular wave of given frequency, it is necessary to calculate the overall motion responses to avoid any near resonance condition. Due to this, Responses Amplitude Operator (RAO) of the motion was calculated for this truss spar in order to establish the motion response in surge, pitch and heave direction. In determining the motions response in all 3 DOF, equation 11 with a structure damping ratio of 5 % has been calculated. Table 4.2 shows the calculated parameters and motion responses due to regular wave.

Table 4.2: Calculated parameters and RAO for each motion

Type of motion	**Natural period, ω_n (s)**	**Total mass, Kg**	**Stiffness, K N/m**	**RAO**
Surge	200	1.25×10^8	2.47×10^5	0.62 m
Heave	28	1.51×10^8	1.69×10^7	0.19 m
Pitch	60	7.44×10^{10}	8.16×10^8	0.07 rads

From the result obtained, it can be concluded that RAO for surge, heave and pitch motion with respect to regular wave condition are 0.62 m, 0.19 m and 0.07 radians respectively. Elaboration of the calculation can be viewed in Appendix E.

For RAO due to random wave, a set of calculation has been conducted using Equation 11 with selected frequencies where maximum forces for each frequency were calculated and RAO of the motions has been constructed. Figure 4.4, 4.5 and 4.6 shows the graphs plotted from the behavior of the structure motion according to the theoretical calculation using selected frequency.

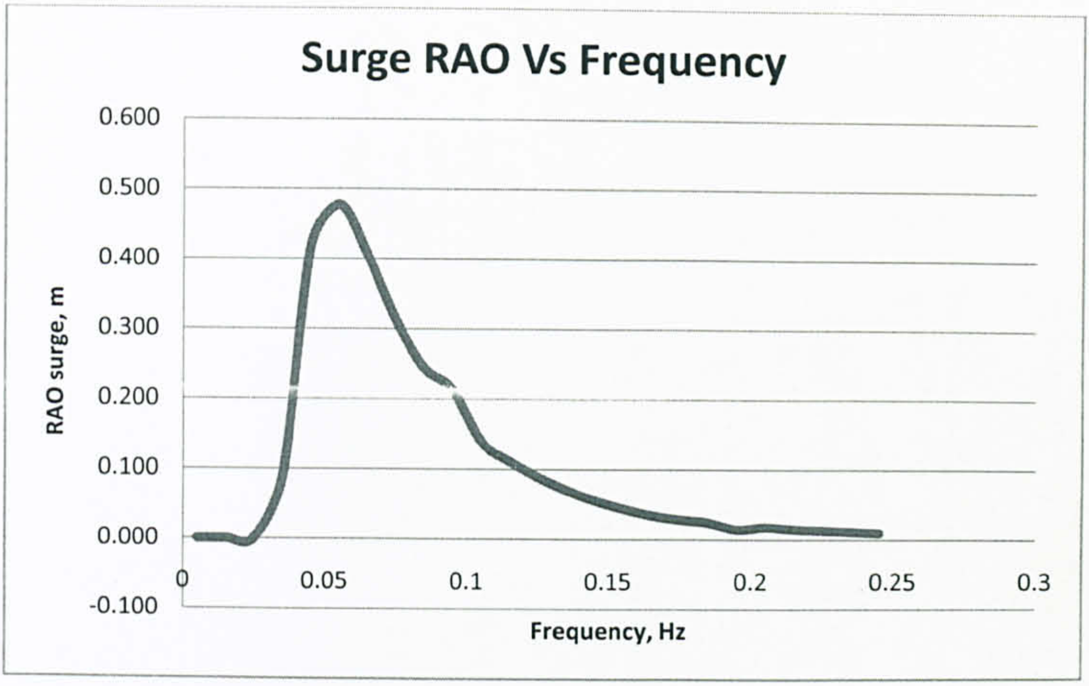

Figure 4.4: Surge motion response

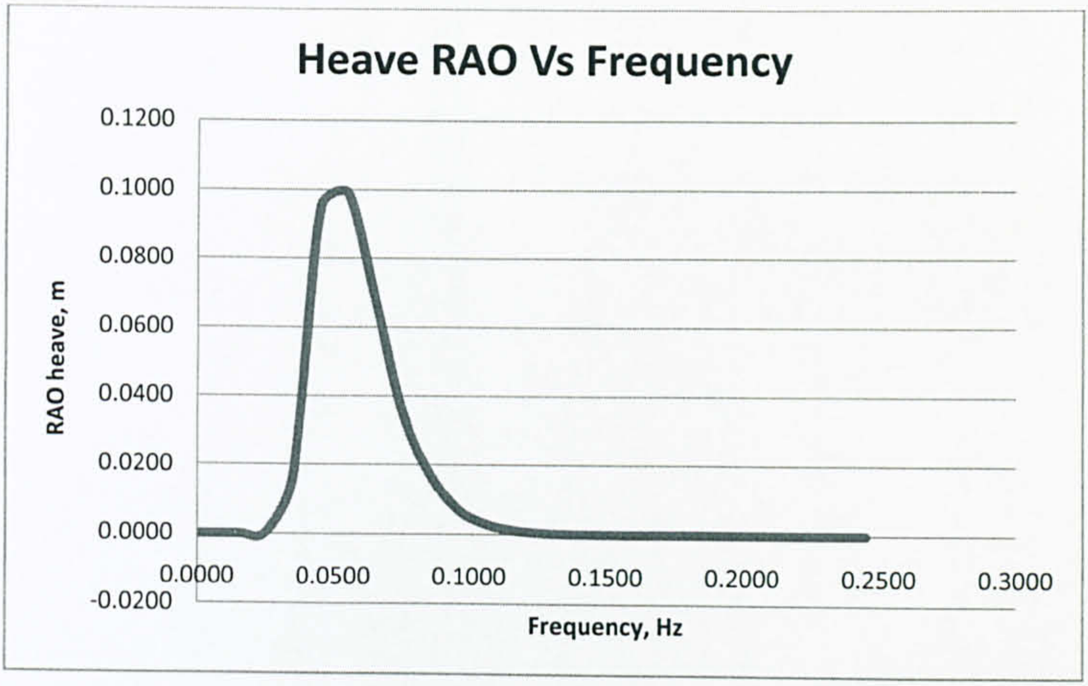

Figure 4.5: Heave motion responses

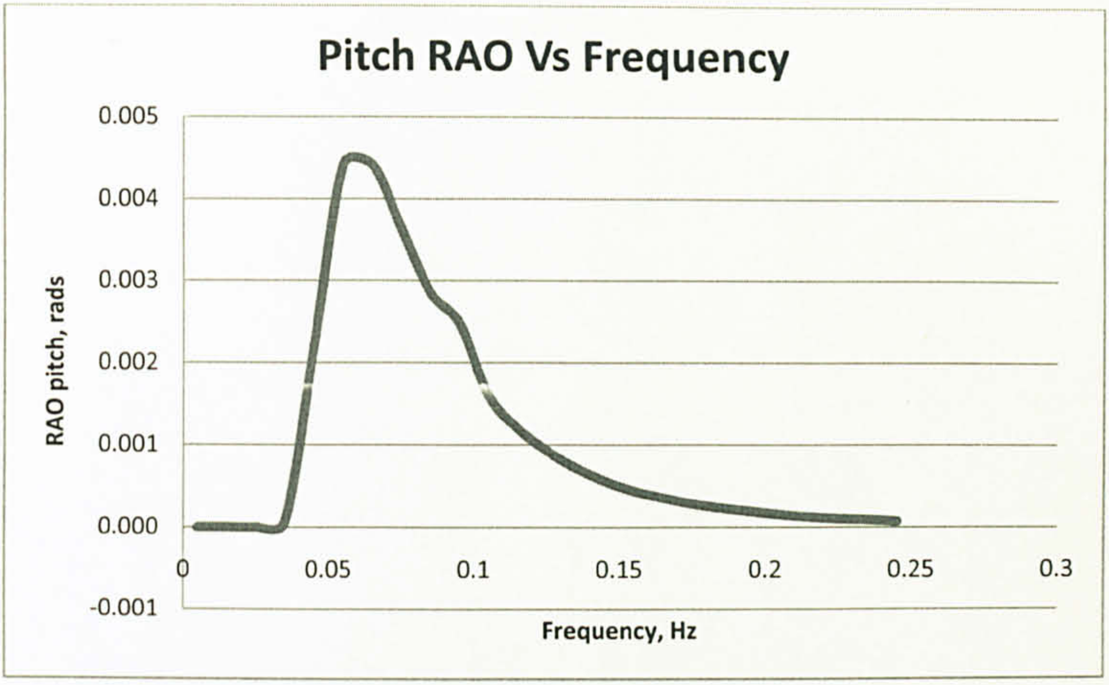

Figure 4.6: Pitch motion response

From Figure 4.4, it is observed that the maximum RAO surge amplitude is 0.5 m. This gives an impression that from the selected frequencies, Holstein spar will have maximum movement of 0.5 m in X axis. The same goes for heave response showed in Figure 4.5 which indicates maximum amplitude of 0.1 m in Y-axis and Figure 4.6 illustrates maximum pitch amplitude of 0.0045 radians in Z-axis. All three maximum amplitudes were observed to be occurred during at the same frequency which is at 0.055 Hz. This can be assumed to be the time where maximum force occurred and gives impact to the response behavior of the structure.

4.3.1 MOTION RESPONSES SPECTRUM

Once motion responses have been obtained, motion spectrum subjected to PM-Spectrum wave is then calculated. Calculated RAO is multiplied to the constructed PM Wave spectrum (S_f), which was elaborately explained in appendix D. Shown below are the energy density spectrum for surge, heave and pitch generated in random wave condition for Holstein spar platform.

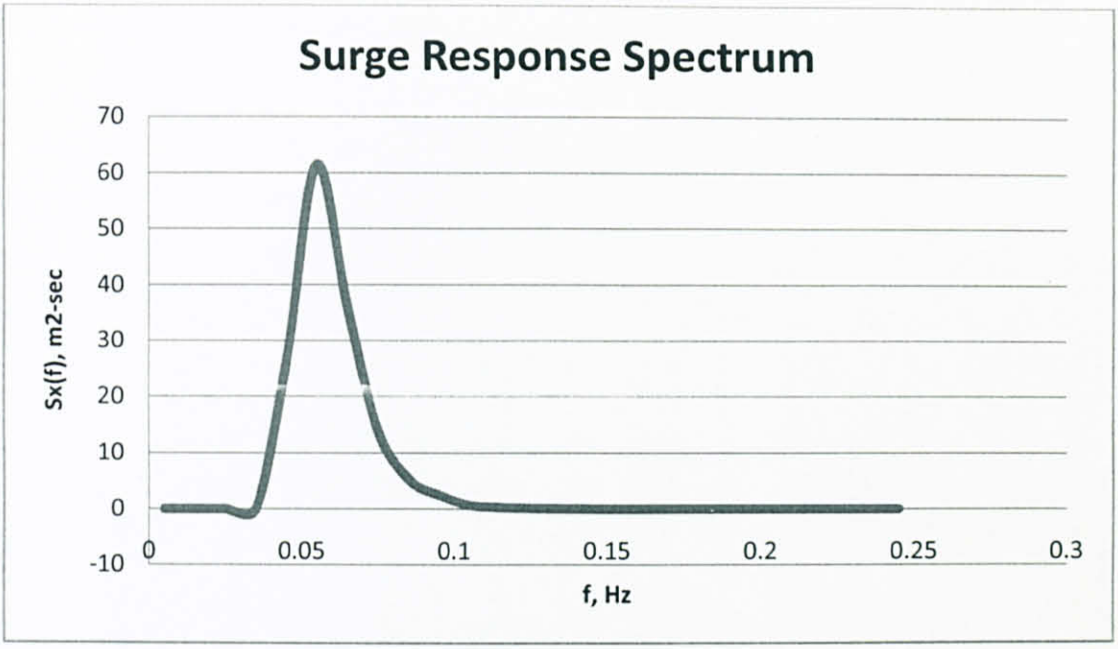

Figure 4.7: Surge response spectrum

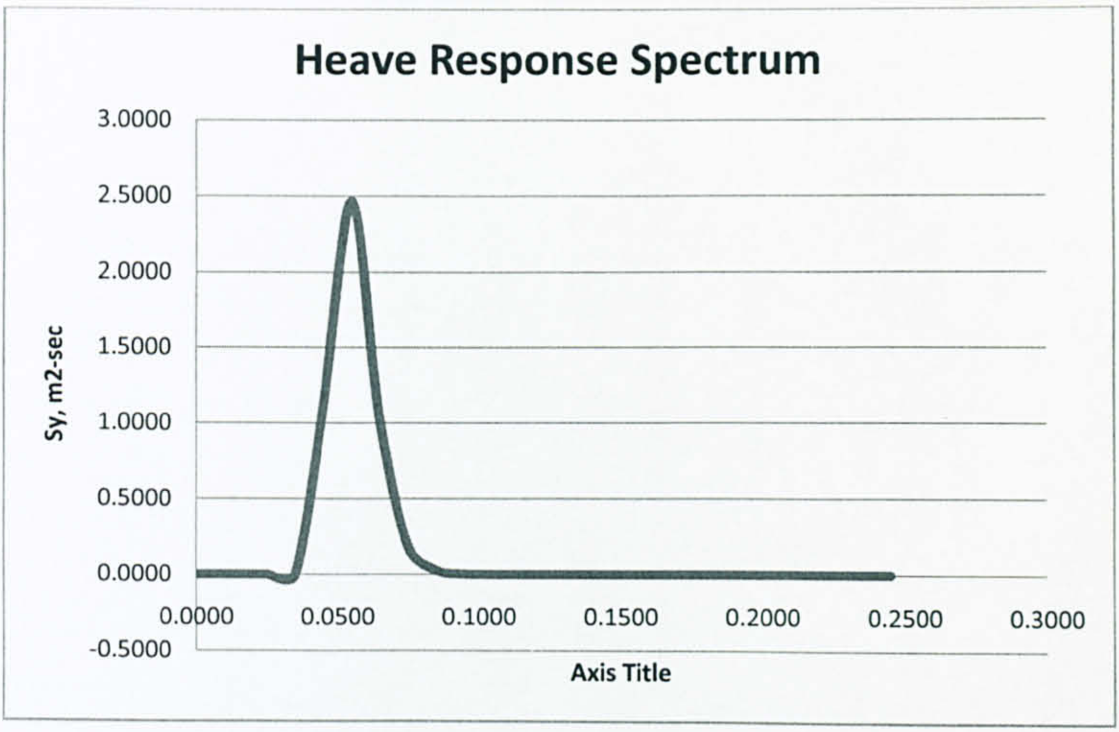

Figure 4.8: Heave motion spectrum

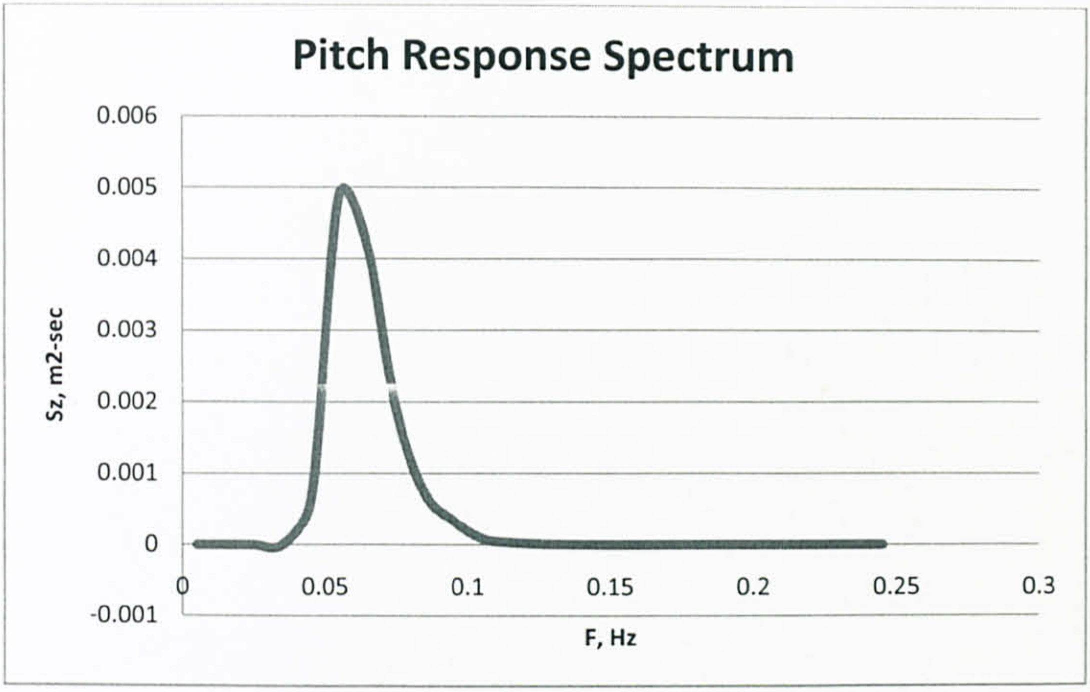

Figure 4.9: Pitch motion spectrum

Energy density of the sea condition indicates that the surge maximum value as 62 m^2-sec, 2.5 m^2-secs for heave and 0.0048 m -secs from Figure 4.7, 4.8 and 4.9 respectively. Surge is observed to have the highest energy density distribution due to the assumption made where the wave acted in unidirectional X direction. This is due to structure movement occurred mostly in X-axis direction. It is proved in the force calculation where force acting in X direction is the highest to the force acting in Y direction and moment in Z direction where it contributed to dominant movement of the structure. This assumption can be proved from the lab experiment conducted in the Offshore Lab where the dominant motion can be observed to be in X direction

4.3.2 MOTION RESPONSE WAVE PROFILE

Wave profile for each response has been generated using the equation stated in equation 10. Below is the wave profile for surge and heave with respect to random wave condition.

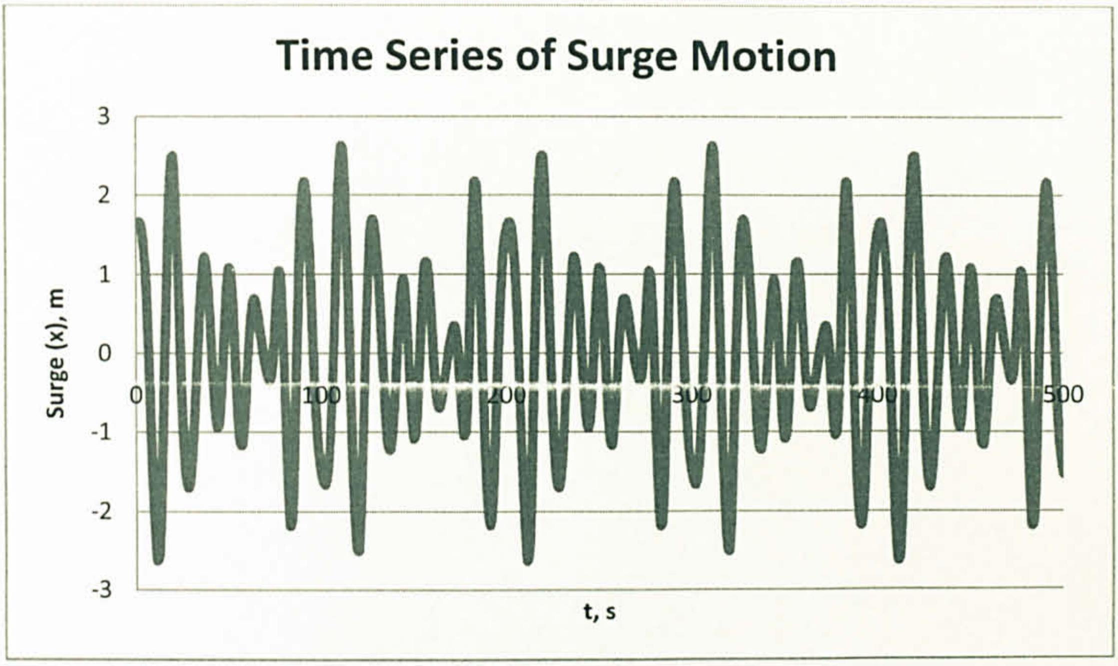

Figure 4.10: Simulated wave profile for surge

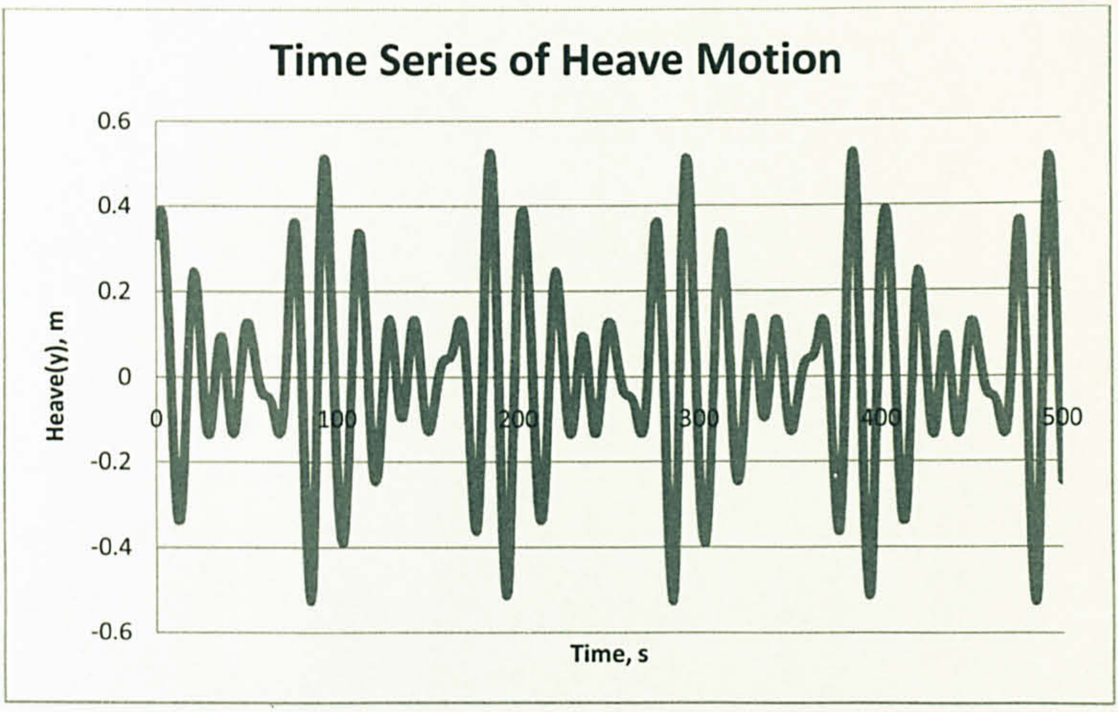

Figure 4.11: Simulated wave profile for Heave

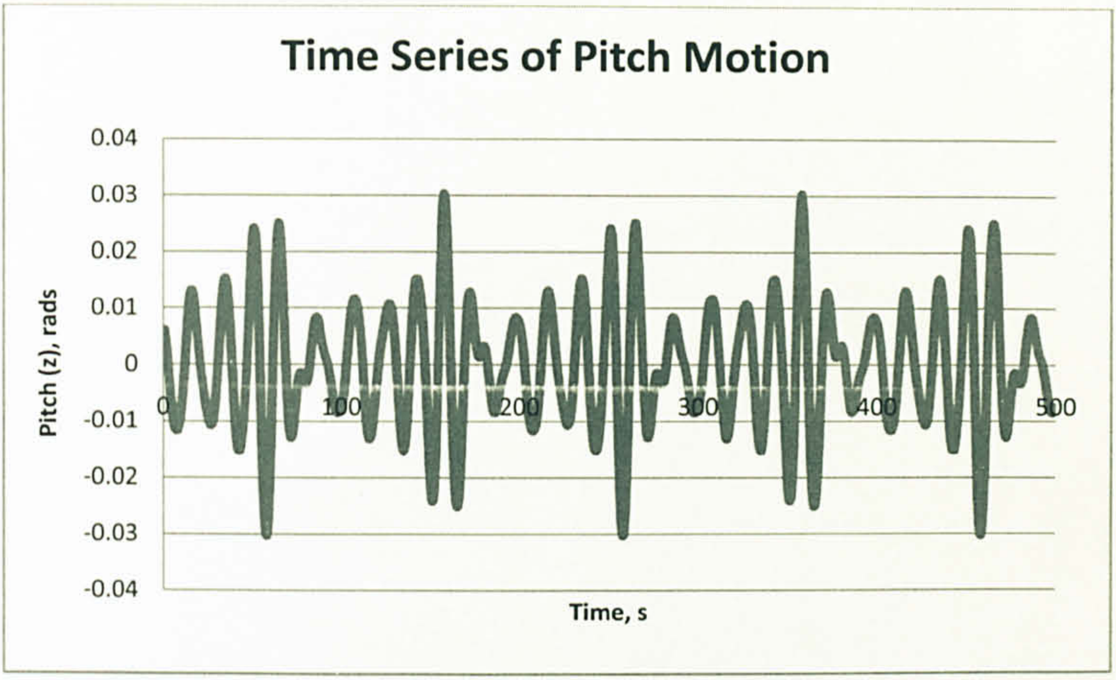

Figure 4.12: Simulated wave profile for Pitch

From Figure 4.10, it shows a wave profile of 500 seconds where the highest surge movement for random condition can go up to 2.5 m. This indicates that in random wave condition, at location of x= 0 m, this spar moves a maximum of 2.5 m in X direction. The value can be considered as acceptable since it is located at Gulf of Mexico where for this study the author has focused on 100 years extreme condition.

Figure 4.11 indicates that heave motion moves maximum up to 0.5 m with respect to the field condition and wave and current loading acting on the structure. This behavior can be assumed due to the heave plate action. Heave motion for spar proved to be smaller due to the three heave plates located at truss section of the spar, thus provide a slower motion in Y direction.

From Figure 4.12, pitch wave profile showed maximum amplitude of 0.03 radians (1.8°). The incident wave which acted on the hull created a moment in clockwise direction but has been countered by opposite force resulted from reflection of the incident wave. This has resulted to the pitch response as shown in the graph.

4.3.3 EXPERIMENTAL ANALYSIS

From lab experiment conducted in the offshore lab, UTP, the behavior of the structure has successfully captured. Trends between actual and calculated response of each motion are as shown below. Appendix I illustrate the detailed information of the responses movement.

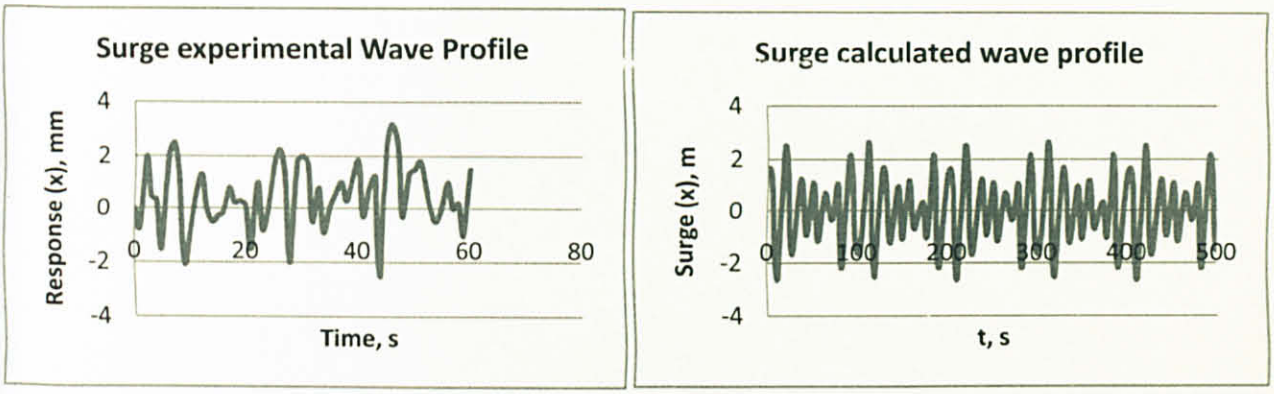

Figure 4.13: Surge comparison between experiment and calculated responses

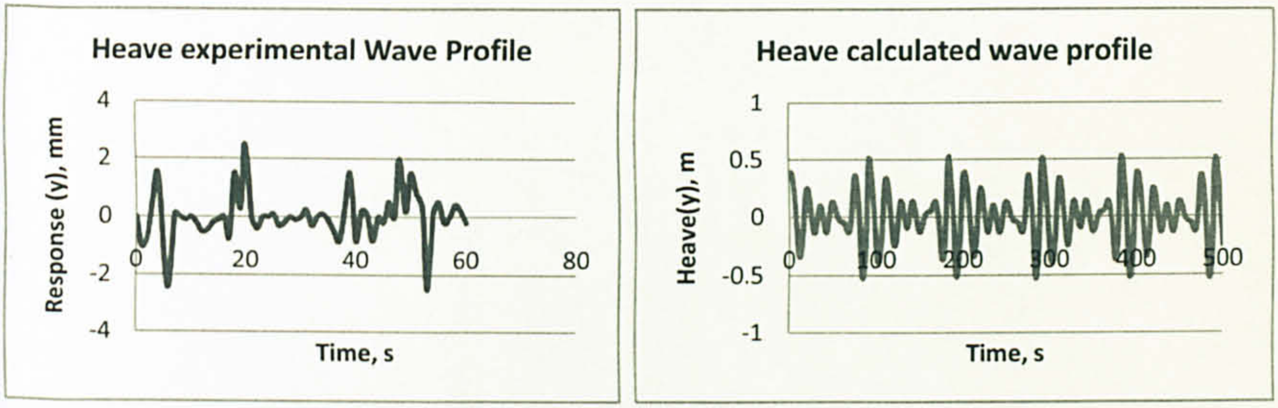

Figure 4.14: Heave comparison between experiment and calculated response

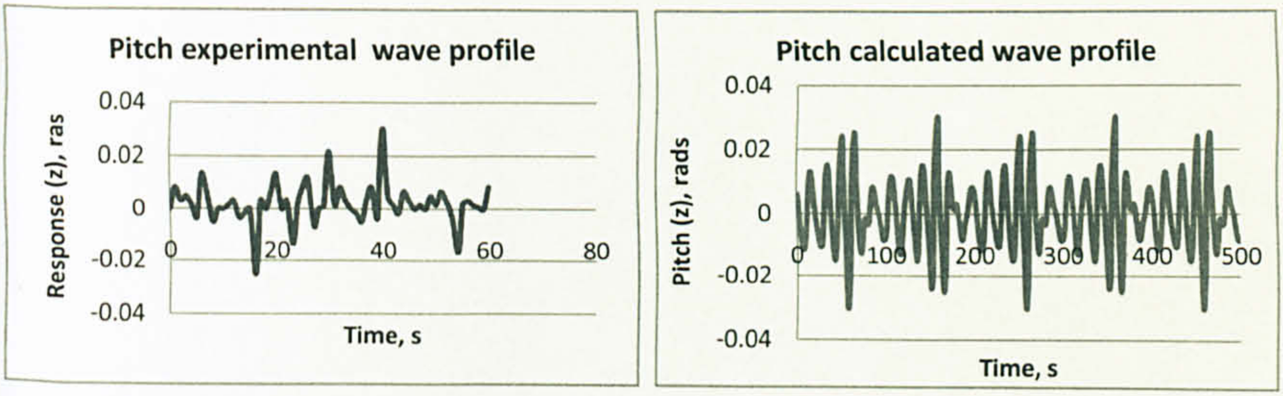

Figure 4.15: Pitch comparison between experiment and calculated response

The above figures indicate that the pattern created from the experimented prototype in the lab gives a similar trend as shown in the theoretical graph from Figure 4.10, 4.11 and 4.12 respectively. Value recorded from the experiment cannot be used to compare between these graphs since the prototype does not resemble Holstein Truss Spar platform in any kind.

Here it can be assumed that theoretical analysis does gives an indication of the real behavior in real situation. The similar trend indicates that the structure behaves approximately the same as calculated in the theoretical and in the experiment. Even though the Offshore Lab might not resemble the real sea condition, it still have similar condition since the wave was generated using P-M Spectrum wave model and can be used to identify the real behavior of the floating structures.

The predicted responses were only an approximate due to certain limitations which are;

1. Usage of Frequency-Domain technique whereby all the nonlinearities in the equations was being replaced with linear approximation.
2. Calculation covers on hard tank section without taking any consideration on the rest of the section of the spar.
3. Computation of stiffness value was simplified using static equilibrium condition due to not enough information on the mooring lines actual stiffness.
4. The mass moments of inertia were calculated based on the assumed distribution of masses.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

From the literature review discussed in this study, the author manages to understand several complete researches from the theories and behaviors of the structure that have been done in the industry . Hydrodynamic analysis conducted in this study has gives an introduction on spar platform behavior due to P-M spectrum wave which was performed using simplified mathematical method. The regular and random wave condition was established for selected structure, Holstein Truss Spar platform located at Gulf of Mexico. The frequency domain analysis clearly illustrated the three degrees of freedom motion which are in surge, heave and pitch for both condition. The procedures and solutions were obtained using specific equations. From the results obtained, this study has successfully demonstrated the predicted behavior of spar platform due to the wave and current loading subjected to PM spectrum wave.

Based on the wave forces computation on the hard tank, several analyses have been performed in order to understand the structure behavior of the selected spar. Below are the summaries conclusions made from the discussion of the previous section:

1. The frequency domain analysis method has the ability to predict the behavior of the truss spar motion in three degree of freedom which are surge, heave and pitch acted upon by a random PM Spectrum wave.
2. PM spectrum wave analysis indicates that Holstein truss spar sea condition having a maximum energy density of 250 m^2-secs which happens at frequency of 0.055 Hz.
3. From all the analysis done to the graph resulted from the computation of the RAO, maximum amplitude for regular wave condition was found out to be 0.62 m, 0.19 m and 0.07 radians for surge, heave and pitch respectively. In random wave condition, maximum amplitude results from the wave profile that has been generated from PM spectrum wave are 2.5 m, 0.5 m, and 0.03 radians for surge,

heave and pitch motions.

4. The observed responses of all three motions indicate maximum frequency of 0.055 Hz where all the maximum amplitude occurs at that frequency. This gives an impression that maximum energy exert on the face of Holstein spar platform occurred at time of 18.182 seconds.
5. The experiments conducted manage to show the response of the structure that was impacted by extreme condition, generated in the Offshore lab. The trend of the responses was discovered to be similar with theoretical results.
6. This study is relevant to be utilized in the industry for preliminary design of spar since the behavior pattern for surge, heave and pitch is found to be fairly identical with similar studies that have been continuously conducted by other researchers from all over the world.

5.2 RECOMMENDATIONS

Due to many limitations and inaccuracy of the results obtain in this research, the author manage to come out with few recommendation for further improvement in the dynamic analysis and future work, as stated below.

- Response amplitude operator (RAO) can be better explained in Time domain analysis compared to frequency domain. This is because it allows a thorough analysis comprises of all system nonlinearities where the established results and findings for spar responses are more accurate.
- For further improvement, the unidirectional waves should be replaced with multi directional waves direction in order to provide a meticulous analysis for the spar. Consideration of all part of the spar is important since it will have a global impact for the spar responses at the end of the study.
- Employment of linear diffraction theory to calculate the inertia force and diffraction force for the main body is better compared to Morison equation where a more established hydrodynamic analysis will be able to develop.
- For further research, it is recommend to compare the obtained responses with other type of spar in order to demonstrate clearly the advantages and disadvantages of all three types of spar.

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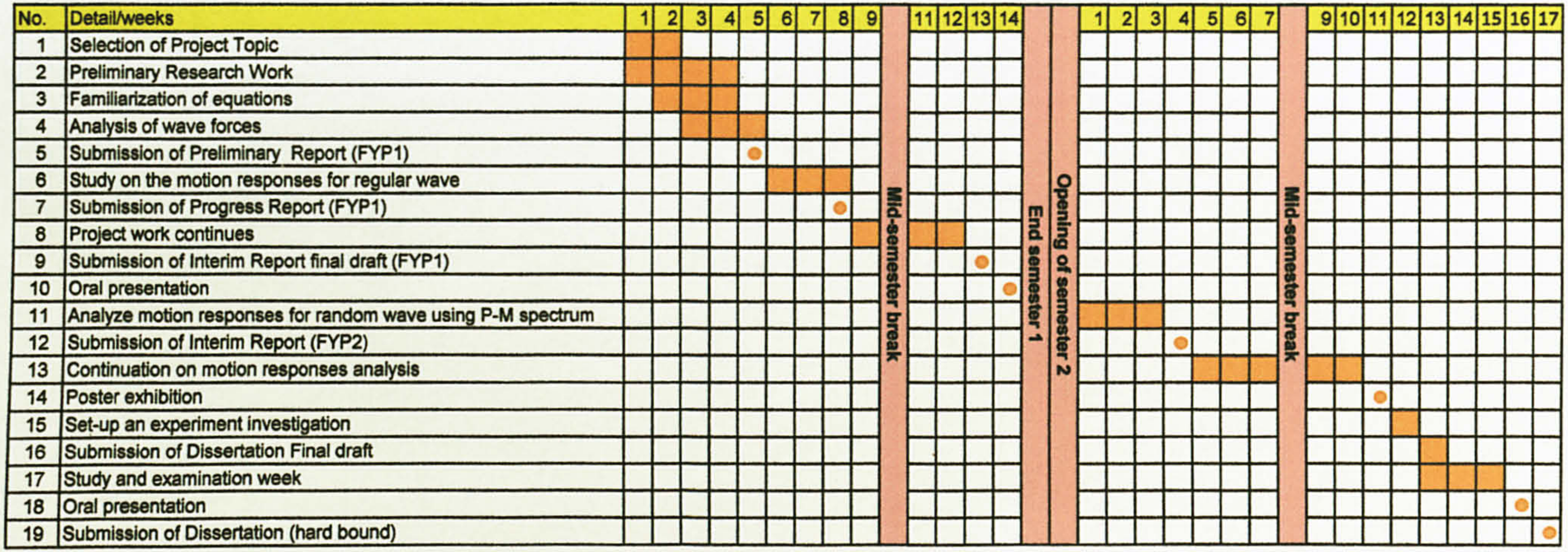
APPENDICES

APPENDIX A

Key Milestone and Gantt Chart



FYP 1 & 2 KEY MILESTONE AND GANTT CHART

APPENDIX B

Wave Force Calculation

DESIGN PARAMETER

Wave Data

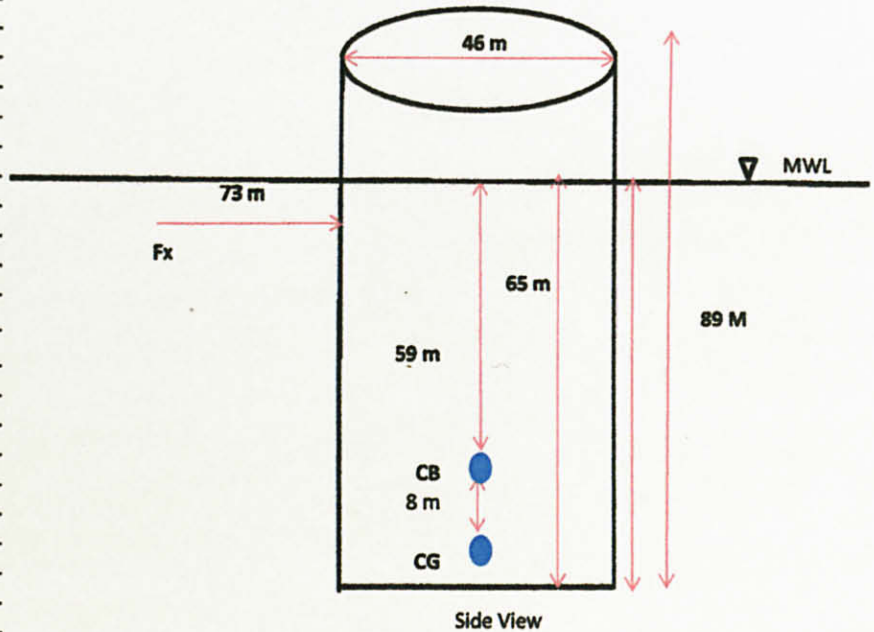
Wave height, Hmax	=	24 m
Wave period, Tass	=	16.7 s
wave length, L	=	435.44 m
Wave number, k	=	0
Wave frequency, ω	=	0.376 rad/s
Cd	=	0.6
Cm	=	2.0

Others

water depth, d	=	1324 m
Hard tank diameter, D	=	46 m
Hard tank length	=	89 m
Gravity acceleration, g	=	9.8067 m/s^2
Sea water density, ρ	=	1030 kg/m^3
Distance fr origin, X	=	0 m
time at x, t	=	0 s

Constant Value

$\theta = kx-\omega t$	=	0
sin theta	=	0
cos theta	=	0
sinh kd	=	100528513.9
Cosh kd	=	100528513.9
H/2	=	24
$\pi H/T$	=	4.51
$2p^2H/T^2$	=	1.70
$(D/2)Cd\rho$	=	16583
$(\pi D^2/4)Cm\rho$	=	3423519.178



MAXIMUM FORCE EXERTED ON HARD TANK

y (m)	s	cosh ks	sinh ks	U	U_o	Drg Force	In.Force	T.FORCE (Fx)
-1	1324.5	99805835.43	99805835.43	0.294916403	1.682800639	1.442317779	5761.100262	5762.54258
-2	1323.5	98376026.77	98376026.77	0.290691459	1.658693002	1.40128878	5678.567302	5679.968591
-3	1322.5	96966701.42	96966701.42	0.286527042	1.634930728	1.361426916	5597.216701	5598.578128
-4	1321.5	95577565.92	95577565.92	0.282422283	1.61150887	1.322698986	5517.031521	5518.35422
-5	1320.5	94208331.05	94208331.05	0.278376329	1.588422551	1.285072732	5437.995066	5439.280139
-6	1319.5	92858711.69	92858711.69	0.274388337	1.565666965	1.248516817	5360.09088	5361.339397
-7	1318.5	91528426.86	91528426.86	0.270457477	1.543237373	1.213000792	5283.302742	5284.515742
-8	1317.5	90217199.55	90217199.55	0.266582929	1.521129105	1.178495076	5207.614662	5208.793157
-9	1316.5	88924756.76	88924756.76	0.262763888	1.499337558	1.144970929	5133.010883	5134.155854
-10	1315.5	87650829.38	87650829.38	0.258999558	1.477858194	1.11240043	5059.475871	5060.588271
-11	1314.5	86395152.15	86395152.15	0.255289156	1.456686542	1.08075645	4986.994313	4988.07507
-12	1313.5	85157463.64	85157463.64	0.251631909	1.435818193	1.050012632	4915.55112	4916.601132
-13	1312.5	83937506.13	83937506.13	0.248027054	1.415248802	1.020143371	4845.131414	4846.151558
-14	1311.5	82735025.61	82735025.61	0.244473843	1.394974085	0.991123788	4775.720535	4776.711659
-15	1310.5	81549771.72	81549771.72	0.240971535	1.374989823	0.962929712	4707.304029	4708.266958
-16	1309.5	80381497.65	80381497.65	0.2375194	1.355291853	0.935537662	4639.867651	4640.803188
-17	1308.5	79229960.16	79229960.16	0.23411672	1.335876074	0.908924821	4573.39736	4574.306285
-18	1307.5	78094919.49	78094919.49	0.230762787	1.316738444	0.883069025	4507.879316	4508.762385
-19	1306.5	76976139.3	76976139.3	0.227456902	1.297874978	0.857948737	4443.299877	4444.157826
-20	1305.5	75873386.64	75873386.64	0.224198376	1.279281747	0.833543035	4379.645597	4380.47914
-21	1304.5	74786431.92	74786431.92	0.220986532	1.260954882	0.809831592	4316.903222	4317.713053
-22	1303.5	73715048.79	73715048.79	0.217820701	1.242890566	0.786794659	4255.059688	4255.846482
-23	1302.5	72659014.2	72659014.2	0.214700223	1.225085037	0.764413047	4194.102118	4194.866531
-24	1301.5	71618108.26	71618108.26	0.211624448	1.207534588	0.742668115	4134.017821	4134.760489
-25	1300.5	70592114.23	70592114.23	0.208592737	1.190235565	0.721541752	4074.794285	4075.515827
-26	1299.5	69580818.5	69580818.5	0.205604458	1.173184367	0.701016362	4016.41918	4017.120196
-27	1298.5	68584010.49	68584010.49	0.202658989	1.156377442	0.681074849	3958.880351	3959.561426
-28	1297.5	67601482.65	67601482.65	0.199755716	1.139811292	0.661700603	3902.165818	3902.827518
-29	1296.5	66633030.41	66633030.41	0.196894035	1.123482467	0.642877488	3846.263771	3846.906649
-30	1295.5	65678452.12	65678452.12	0.19407335	1.107387567	0.624589827	3791.162572	3791.787162
-31	1294.5	64737549.03	64737549.03	0.191293074	1.09152324	0.606822387	3736.850747	3737.457569
-32	1293.5	63810125.22	63810125.22	0.188552628	1.075886185	0.589560369	3683.316988	3683.906548
-33	1292.5	62895987.6	62895987.6	0.185851442	1.060473145	0.572789397	3630.550149	3631.122938
-34	1291.5	61994945.82	61994945.82	0.183188952	1.04528091	0.556495501	3578.539242	3579.095737
-35	1290.5	61106812.28	61106812.28	0.180564605	1.030306318	0.540665111	3527.273438	3527.814103
-36	1289.5	60231402.06	60231402.06	0.177977854	1.01554625	0.525285042	3476.742063	3477.267348
-37	1288.5	59368532.87	59368532.87	0.175428161	1.000997634	0.510342482	3426.934596	3427.444938
-38	1287.5	58518025.07	58518025.07	0.172914994	0.986657439	0.495824987	3377.840665	3378.33649
-39	1286.5	57679701.55	57679701.55	0.170437831	0.972522681	0.481720466	3329.45005	3329.93177
-40	1285.5	56853387.78	56853387.78	0.167996155	0.958590416	0.468017169	3281.752674	3282.220691
-41	1284.5	56038911.7	56038911.7	0.165589459	0.944857743	0.454703684	3234.738605	3235.193309
-42	1283.5	55236103.72	55236103.72	0.16321724	0.931321804	0.441768923	3188.398056	3188.839825
-43	1282.5	54444796.69	54444796.69	0.160879006	0.917979778	0.429202111	3142.721377	3143.150579
-44	1281.5	53664825.85	53664825.85	0.158574269	0.90482889	0.416992782	3097.699057	3098.11605
-45	1280.5	52896028.8	52896028.8	0.15630255	0.891866399	0.405130766	3053.321723	3053.726853
-46	1279.5	52138245.46	52138245.46	0.154063374	0.879089608	0.393606184	3009.580134	3009.97374
-47	1278.5	51391318.04	51391318.04	0.151856278	0.866495857	0.382409437	2966.465183	2966.847592
-48	1277.5	50655091.04	50655091.04	0.149680799	0.854082521	0.371531199	2923.967892	2924.339423
-49	1276.5	49929411.15	49929411.15	0.147536487	0.841847019	0.360962409	2882.079414	2882.440376
-50	1275.5	49214127.28	49214127.28	0.145422894	0.8297868	0.350694266	2840.791025	2841.14172
-51	1274.5	48509090.5	48509090.5	0.143339579	0.817899356	0.340718215	2800.094131	2800.434849
-52	1273.5	47814154	47814154	0.141286111	0.80618221	0.33102595	2759.980255	2760.311281
-53	1272.5	47129173.1	47129173.1	0.13926206	0.794632922	0.321609396	2720.441048	2720.762657
-54	1271.5	46454005.17	46454005.17	0.137267005	0.783249088	0.312460711	2681.468275	2681.780736
-55	1270.5	45788509.63	45788509.63	0.135300531	0.772028338	0.303572274	2643.053822	2643.357395
-56	1269.5	45132547.91	45132547.91	0.133362229	0.760968336	0.294936683	2605.189691	2605.484628
-57	1268.5	44485983.44	44485983.44	0.131451695	0.750066778	0.286546745	2567.867998	2568.154545
-58	1267.5	43848681.58	43848681.58	0.129568531	0.739321394	0.278395472	2531.080972	2531.359367
-59	1266.5	43220509.65	43220509.65	0.127712344	0.728729948	0.270476075	2494.820953	2495.091429
-60	1265.5	42601336.85	42601336.85	0.12588275	0.718290234	0.262781958	2459.080392	2459.343174
-61	1264.5	41991034.26	41991034.26	0.124079366	0.708000078	0.255306711	2423.851846	2424.107153
-62	1263.5	41389474.8	41389474.8	0.122301817	0.697857338	0.24804411	2389.127981	2389.376025
-63	1262.5	40796533.23	40796533.23	0.120549733	0.687859902	0.240988105	2354.901567	2355.142555
-64	1261.5	40212086.08	40212086.08	0.118822749	0.678005688	0.23413282	2321.165477	2321.39961
-65	1260.5	39636011.66	39636011.66	0.117120506	0.668292645	0.227472543	2287.912687	2288.14016
-66	1259.5	39068190.02	39068190.02	0.115442649	0.65871875	0.221001729	2255.136274	2255.357275
-67	1258.5	38508502.95	38508502.95	0.113788829	0.649282009	0.214714987	2222.829411	2223.044126
-68	1257.5	37956833.9	37956833.9	0.112158702	0.639980459	0.208607081	2190.985374	2191.193981
-69	1256.5	37413068	37413068	0.110551927	0.630812161	0.202672925	2159.597532	2159.800205
-70	1255.5	36877092.04	36877092.04	0.108968171	0.621775208	0.196907575	2128.659348	2128.856256
-71	1254.5	36348794.42	36348794.42	0.107407104	0.612867717	0.191306229	2098.164382	2098.355689
-72	1253.5	35828065.14	35828065.14	0.1058684	0.604087834	0.185864222	2068.106284	2068.292149
-73	1252.5	35314795.78	35314795.78	0.104351739	0.59543373	0.180577022	2038.478796	2038.659373

SUMMARY OF WAVE FORCES WITH RESPECT TO TIME

Total Force

t	0	1.7	2.7	3.7	4.7	5.7	6.7	7.7	8.7	9.7	10.7	11.7	12.7	13.7	14.7	15.7	16.7
1248.5	37.1667	-1127.055	-1628.62	-1896.445	-1892.267	-420.2241	-1630.486	-501.8844	216.6703	909.4935	1476.403	1832.714	1924.314	1749.751	1337.723	740.6659	37.1667
1249.5	38.25492	-1143.083	-1652.138	-1923.99	-1919.79	-432.7837	-1654.345	-509.6948	219.2808	922.2938	1497.641	1859.299	1952.284	1775.282	1357.457	751.9048	38.25492
1250.5	39.37501	-1159.334	-1675.994	-1951.936	-1947.714	-445.7194	-1678.556	-517.6338	221.9135	935.2679	1519.181	1886.27	1980.662	1801.188	1377.487	763.3211	39.37501
1251.5	40.52789	-1175.81	-1700.192	-1980.287	-1976.045	-459.0425	-1703.123	-525.7037	224.5682	948.4179	1541.027	1913.631	2009.451	1827.473	1397.817	774.9175	40.52789
1252.5	41.71452	-1192.514	-1724.737	-2009.05	-2004.788	-472.7645	-1728.053	-533.9069	227.2448	961.7461	1563.185	1941.388	2038.659	1854.143	1418.452	786.6971	41.71452
1253.5	42.9359	-1209.451	-1749.634	-2038.231	-2033.949	-486.8976	-1753.35	-542.2458	229.9431	975.2546	1585.657	1969.547	2068.292	1881.204	1439.395	798.6631	42.9359
1254.5	44.19304	-1226.621	-1774.887	-2067.834	-2063.536	-501.4541	-1779.02	-550.7228	232.663	988.9458	1608.449	1998.114	2098.356	1908.661	1460.653	810.8186	44.19304
1255.5	45.48699	-1244.03	-1800.503	-2097.868	-2093.552	-516.4467	-1805.068	-559.3405	235.4041	1002.822	1631.564	2027.094	2128.856	1936.521	1482.23	823.1668	45.48699
1256.5	46.81882	-1261.679	-1826.485	-2128.337	-2124.006	-531.8885	-1831.501	-568.1015	238.1663	1016.885	1655.008	2056.493	2159.8	1964.79	1504.13	835.711	46.81882
1257.5	48.18966	-1279.572	-1852.84	-2159.249	-2154.903	-547.793	-1858.323	-577.0082	240.9494	1031.137	1678.785	2086.318	2191.194	1993.472	1526.359	848.4545	48.18966
1258.5	49.60062	-1297.712	-1879.572	-2190.61	-2186.25	-564.1743	-1885.542	-586.0634	243.7531	1045.581	1702.899	2116.575	2223.044	2022.576	1548.922	861.4007	49.60062
1259.5	51.0529	-1316.102	-1906.687	-2222.425	-2218.054	-581.0466	-1913.162	-595.2698	246.5771	1060.22	1727.355	2147.269	2255.357	2052.106	1571.824	874.553	51.0529
1260.5	52.54771	-1334.746	-1934.19	-2254.702	-2250.32	-598.4247	-1941.19	-604.6302	249.421	1075.054	1752.158	2178.407	2288.14	2082.069	1595.07	887.915	52.54771
1261.5	54.08627	-1353.646	-1962.086	-2287.448	-2283.056	-616.3239	-1969.632	-614.1474	252.2847	1090.088	1777.313	2209.996	2321.4	2112.472	1618.666	901.4903	54.08627
1262.5	55.66989	-1372.807	-1990.382	-2320.669	-2316.269	-634.7599	-1998.493	-623.8243	255.1676	1105.322	1802.824	2242.042	2355.143	2143.321	1642.617	915.2826	55.66989
1263.5	57.29988	-1392.231	-2019.083	-2354.372	-2349.966	-653.7488	-2027.782	-633.6637	258.0695	1120.76	1828.696	2274.552	2389.376	2174.623	1666.928	929.2954	57.29988
1264.5	58.97759	-1411.922	-2048.194	-2388.564	-2384.153	-673.3074	-2057.503	-643.6689	260.99	1136.405	1854.935	2307.532	2424.107	2206.383	1691.606	943.5328	58.97759
1265.5	60.70442	-1431.883	-2077.721	-2423.252	-2418.838	-693.4528	-2087.663	-653.8427	263.9286	1152.257	1881.546	2340.988	2459.343	2238.61	1716.655	957.9984	60.70442
1266.5	62.48181	-1452.118	-2107.67	-2458.443	-2454.028	-714.2027	-2118.269	-664.1883	266.8849	1168.321	1908.532	2374.929	2495.091	2271.311	1742.083	972.6963	62.48181
1267.5	64.31125	-1472.631	-2138.048	-2494.145	-2489.731	-735.5753	-2149.327	-674.709	269.8584	1184.598	1935.901	2409.361	2531.359	2304.491	1767.893	987.6306	64.31125
1268.5	66.19425	-1493.423	-2168.859	-2530.366	-2525.953	-757.5896	-2180.845	-685.408	272.8486	1201.091	1963.657	2444.29	2568.155	2338.158	1794.093	1002.805	66.19425
1269.5	68.13238	-1514.501	-2200.111	-2567.111	-2562.703	-780.2648	-2212.83	-696.2887	275.855	1217.803	1991.804	2479.725	2605.485	2372.32	1820.689	1018.224	68.13238
1270.5	70.12726	-1535.866	-2231.808	-2604.39	-2599.989	-803.6209	-2245.287	-707.3544	278.877	1234.736	2020.35	2515.672	2643.357	2406.983	1847.686	1033.892	70.12726
1271.5	72.18055	-1557.523	-2263.959	-2642.21	-2637.817	-827.6785	-2278.225	-718.6086	281.914	1251.892	2049.298	2552.138	2681.781	2442.156	1875.092	1049.814	72.18055
1272.5	74.29396	-1579.475	-2296.568	-2680.579	-2676.196	-852.4589	-2311.651	-730.0548	284.9654	1269.275	2078.655	2589.132	2720.763	2477.845	1902.912	1065.992	74.29396
1273.5	76.46925	-1601.726	-2329.642	-2719.504	-2715.135	-877.9838	-2345.571	-741.6968	288.0305	1286.886	2108.426	2626.66	2760.311	2514.059	1931.153	1082.433	76.46925
1274.5	78.70823	-1624.28	-2363.188	-2758.994	-2754.64	-904.2759	-2379.994	-753.5382	291.1087	1304.729	2138.617	2664.731	2800.435	2550.805	1959.821	1099.141	78.70823
1275.5	81.01276	-1647.14	-2397.213	-2799.057	-2794.721	-931.3583	-2414.927	-765.5827	294.1991	1322.806	2169.234	2703.353	2841.142	2588.091	1988.924	1116.12	81.01276
1276.5	83.38477	-1670.311	-2431.723	-2839.701	-2835.386	-959.255	-2450.378	-777.8343	297.301	1341.12	2200.282	2742.532	2882.44	2625.925	2018.468	1133.375	83.38477
1277.5	85.82624	-1693.796	-2466.724	-2880.935	-2876.643	-987.9907	-2486.354	-790.2969	300.4137	1359.673	2231.767	2782.278	2924.339	2664.316	2048.46	1150.911	85.82624
1278.5	88.33918	-1717.599	-2502.225	-2922.767	-2918.501	-1017.591	-2522.864	-802.9745	303.5362	1378.469	2263.695	2822.598	2966.848	2703.271	2078.907	1168.733	88.33918
1279.5	90.92571	-1741.724	-2538.231	-2965.205	-2960.969	-1048.081	-2559.916	-815.8713	306.6677	1397.509	2296.072	2863.5	3009.974	2742.799	2109.816	1186.846	90.92571
1280.5	93.58796	-1766.176	-2574.749	-3008.259	-3004.056	-1079.49	-2597.517	-828.9914	309.8073	1416.797	2328.905	2904.993	3053.727	2782.909	2141.195	1205.256	93.58796
1281.5	96.32817	-1790.957	-2611.788	-3051.938	-3047.771	-1111.843	-2635.676	-842.3391	312.9538	1436.335	2362.199	2947.086	3098.116	2823.608	2173.05	1223.967	96.32817
1282.5	99.14861	-1816.073	-2649.354	-3096.251	-3092.122	-1145.171	-2674.402	-855.9189	316.1064	1456.127	2395.96	2989.787	3143.151	2864.907	2205.391	1242.985	99.14861
1283.5	102.0516	-1841.527	-2687.454	-3141.206	-3137.119	-1179.503	-2713.703	-869.7352	319.264	1476.174	2430.196	3033.104	3188.84	2906.813	2238.223	1262.315	102.0516
1284.5	105.0396	-1867.323	-2726.096	-3186.813	-3182.773	-1214.87	-2753.587	-883.7926	322.4254	1496.48	2464.912	3077.048	3235.193	2949.337	2271.556	1281.963	105.0396
1285.5	108.1152	-1893.466	-2765.287	-3233.081	-3229.091	-1251.302	-2794.064	-898.0958	325.5894	1517.048	2500.115	3121.625	3282.221	2992.486	2305.396	1301.935	108.1152
1286.5	111.2807	-1919.959	-2805.036	-3280.021	-3276.085	-1288.832	-2835.143	-912.6496	328.7548	1537.88	2535.811	3166.847	3329.932	3036.271	2339.753	1322.237	111.2807
1287.5	114.5389	-1946.808	-2845.349	-3327.641	-3323.763	-1327.494	-2876.833	-927.4588	331.9204	1558.979	2572.007	3212.721	3378.336	3080.701	2374.633	1342.874	114.5389
1288.5	117.8926	-1974.016	-2886.235	-3375.952	-3372.136	-1367.322	-2919.143	-942.5285	335.0848	1580.347	2608.711	3259.257	3427.445	3125.785	2410.046	1363.852	117.8926

1289.5	121.3444	-2001.587	-2927.701	-3424.964	-3421.214	-1408.352	-2962.082	-957.8638	338.2466	1601.989	2645.927	3306.466	3477.267	3171.534	2446.001	1385.178	121.3444
1290.5	124.8973	-2029.527	-2969.756	-3474.686	-3471.007	-1450.621	-3005.661	-973.4699	341.4042	1623.907	2683.664	3354.355	3527.814	3217.957	2482.505	1406.858	124.8973
1291.5	128.5542	-2057.839	-3012.407	-3525.129	-3521.526	-1494.165	-3049.888	-989.3521	344.5564	1646.103	2721.929	3402.936	3579.096	3265.064	2519.567	1428.899	128.5542
1292.5	132.3182	-2086.527	-3055.664	-3576.304	-3572.781	-1539.025	-3094.774	-1005.516	347.7013	1668.58	2760.728	3452.218	3631.123	3312.866	2557.197	1451.306	132.3182
1293.5	136.1925	-2115.597	-3099.533	-3628.221	-3624.783	-1585.241	-3140.329	-1021.967	350.8374	1691.342	2800.069	3502.211	3683.907	3361.373	2595.403	1474.087	136.1925
1294.5	140.1801	-2145.053	-3144.025	-3680.89	-3677.544	-1632.853	-3186.562	-1038.711	353.9629	1714.391	2839.958	3552.925	3737.458	3410.595	2634.195	1497.249	140.1801
1295.5	144.2845	-2174.899	-3189.146	-3734.324	-3731.073	-1681.905	-3233.485	-1055.753	357.0761	1737.73	2880.404	3604.371	3791.787	3460.543	2673.583	1520.798	144.2845
1296.5	148.5091	-2205.139	-3234.907	-3788.531	-3785.383	-1732.441	-3281.108	-1073.101	360.175	1761.362	2921.413	3656.559	3846.907	3511.229	2713.574	1544.742	148.5091
1297.5	152.8573	-2235.779	-3281.316	-3843.525	-3840.485	-1784.507	-3329.441	-1090.759	363.2578	1785.29	2962.993	3709.499	3902.828	3562.662	2754.181	1569.087	152.8573
1298.5	157.3329	-2266.823	-3328.381	-3899.316	-3896.389	-1838.149	-3378.495	-1108.734	366.3223	1809.517	3005.152	3763.203	3959.561	3614.855	2795.412	1593.842	157.3329
1299.5	161.9396	-2298.276	-3376.112	-3955.916	-3953.109	-1893.415	-3428.282	-1127.032	369.3666	1834.046	3047.897	3817.681	4017.12	3667.818	2837.277	1619.014	161.9396
1300.5	166.6811	-2330.143	-3424.518	-4013.336	-4010.656	-1950.356	-3478.813	-1145.66	372.3883	1858.879	3091.235	3872.945	4075.516	3721.564	2879.786	1644.611	166.6811
1301.5	171.5614	-2362.427	-3473.608	-4071.589	-4069.042	-2009.024	-3530.099	-1164.625	375.3852	1884.02	3135.176	3929.006	4134.76	3776.103	2922.951	1670.64	171.5614
1302.5	176.5846	-2395.134	-3523.391	-4130.686	-4128.28	-2069.47	-3582.151	-1183.933	378.355	1909.471	3179.726	3985.875	4194.867	3831.448	2966.782	1697.109	176.5846
1303.5	181.7549	-2428.269	-3573.878	-4190.64	-4188.381	-2131.751	-3634.981	-1203.592	381.2951	1935.236	3224.895	4043.563	4255.846	3887.612	3011.289	1724.027	181.7549
1304.5	187.0766	-2461.837	-3625.077	-4251.462	-4249.358	-2195.923	-3688.602	-1223.608	384.2031	1961.316	3270.688	4102.082	4317.713	3944.605	3056.484	1751.403	187.0766
1305.5	192.5541	-2495.842	-3676.999	-4313.166	-4311.225	-2262.044	-3743.026	-1243.989	387.0762	1987.716	3317.116	4161.445	4380.479	4002.442	3102.377	1779.244	192.5541
1306.5	198.192	-2530.289	-3729.652	-4375.765	-4373.995	-2330.174	-3798.264	-1264.742	389.9117	2014.438	3364.187	4221.663	4444.158	4061.133	3148.98	1807.56	198.192
1307.5	203.995	-2565.183	-3783.048	-4439.27	-4437.679	-2400.376	-3854.329	-1285.875	392.7067	2041.485	3411.908	4282.749	4508.762	4120.693	3196.305	1836.359	203.995
1308.5	209.9678	-2600.529	-3837.196	-4503.696	-4502.293	-2472.714	-3911.235	-1307.396	395.4582	2068.86	3460.288	4344.714	4574.306	4181.134	3244.364	1865.651	209.9678
1309.5	216.1156	-2636.333	-3892.107	-4569.055	-4567.849	-2547.254	-3968.993	-1329.312	398.1631	2096.566	3509.336	4407.572	4640.803	4242.47	3293.168	1895.444	216.1156
1310.5	222.4433	-2672.598	-3947.791	-4635.362	-4634.361	-2624.064	-4027.618	-1351.632	400.8183	2124.604	3559.06	4471.335	4708.267	4304.714	3342.729	1925.749	222.4433
1311.5	228.9563	-2709.33	-4004.258	-4702.629	-4701.844	-2703.215	-4087.122	-1374.365	403.4204	2152.979	3609.47	4536.016	4776.712	4367.879	3393.061	1956.576	228.9563
1312.5	235.6601	-2746.535	-4061.519	-4770.871	-4770.311	-2784.78	-4147.519	-1397.518	405.9659	2181.694	3660.574	4601.628	4846.152	4431.981	3444.175	1987.933	235.6601
1313.5	242.5601	-2784.216	-4119.585	-4840.101	-4839.777	-2868.834	-4208.824	-1421.101	408.4513	2210.75	3712.38	4668.184	4916.601	4497.031	3496.085	2019.832	242.5601
1314.5	249.6621	-2822.38	-4178.466	-4910.335	-4910.257	-2955.454	-4271.049	-1445.122	410.8728	2240.15	3764.899	4735.698	4988.075	4563.046	3548.803	2052.282	249.6621
1315.5	256.9721	-2861.031	-4238.174	-4981.586	-4981.765	-3044.721	-4334.21	-1469.591	413.2266	2269.899	3818.139	4804.184	5060.588	4630.04	3602.344	2085.294	256.9721
1316.5	264.4961	-2900.175	-4298.721	-5053.869	-5054.316	-3136.718	-4398.32	-1494.518	415.5087	2299.997	3872.11	4873.655	5134.156	4698.027	3656.72	2118.88	264.4961
1317.5	272.2404	-2939.815	-4360.116	-5127.2	-5127.927	-3231.529	-4463.395	-1519.911	417.7149	2330.448	3926.82	4944.126	5208.793	4767.023	3711.945	2153.049	272.2404
1318.5	280.2114	-2979.959	-4422.372	-5201.592	-5202.611	-3329.244	-4529.449	-1545.78	419.8409	2361.254	3982.28	5015.61	5284.516	4837.042	3768.034	2187.814	280.2114
1319.5	288.4159	-3020.61	-4485.5	-5277.062	-5278.386	-3429.953	-4596.498	-1572.136	421.8824	2392.418	4038.498	5088.122	5361.339	4908.1	3825.001	2223.186	288.4159
1320.5	296.8605	-3061.774	-4549.512	-5353.625	-5355.266	-3533.75	-4664.557	-1598.989	423.8346	2423.943	4095.485	5161.676	5439.28	4980.214	3882.86	2259.177	296.8605
1321.5	305.5525	-3103.457	-4614.42	-5431.297	-5433.269	-3640.732	-4733.642	-1626.35	425.6928	2455.831	4153.25	5236.288	5518.354	5053.398	3941.627	2295.799	305.5525
1322.5	314.4989	-3145.662	-4680.236	-5510.094	-5512.41	-3751.001	-4803.768	-1654.229	427.452	2488.085	4211.803	5311.973	5598.578	5127.669	4001.316	2333.063	314.4989
1323.5	323.7072	-3188.397	-4746.971	-5590.031	-5592.706	-3864.659	-4874.953	-1682.637	429.1072	2520.706	4271.155	5388.745	5679.969	5203.044	4061.943	2370.984	323.7072
1324.5	333.1852	-3231.664	-4814.639	-5671.127	-5674.175	-3981.814	-4947.213	-1711.586	430.653	2553.699	4331.314	5466.62	5762.543	5279.539	4123.523	2409.573	333.1852
1318.5	230.6628	-2718.858	-4018.915	-4720.095	-4719.367	-4102.577	-2946.951	-1380.282	404.081	2160.335	3622.553	4552.809	317.0669	4384.283	3406.137	1964.593	230.6628
1319.5	244.6314	-2795.411	-4136.849	-4860.691	-4860.438	-4227.062	-3039.56	-1428.133	409.1716	2219.377	3727.781	4687.977	326.557	4516.382	3511.533	2029.335	244.6314
1320.5	259.4459	-2873.971	-4258.181	-5005.468	-5005.734	-4355.387	-3135.216	-1477.815	413.9924	2279.852	3835.975	4827.137	336.3321	4652.5	3620.302	2096.38	259.4459
1321.5	275.1575	-2954.582	-4383.007	-5154.55	-5155.383	-4487.675	-3234.027	-1529.409	418.5096	2341.783	3947.215	4970.407	346.4008	4792.762	3732.559	2165.819	275.1575
1322.5	291.8206	-3037.288	-4511.424	-5308.064	-5309.515	-4624.052	-3336.105	-1582.996	422.6873	2405.194	4061.579	5117.906	356.7719	4937.298	3848.422	2237.747	291.8206
1323.5	309.4928	-3122.131	-4643.529	-5466.142	-5468.265	-4764.648	-3441.567	-1638.663	426.4864	2470.106	4179.15	5269.758	367.4547	5086.239	3968.014	2312.264	309.4928
1324.5	328.2352	-3209.156	-4779.425	-5628.92	-5631.773	-4909.599	-3550.534	-1696.503	429.8653	2536.54	4300.01	5426.09	378.4586	5239.723	4091.463	2389.473	328.2352

Maximum Force

333.1852	-1127.055	-1628.62	-1896.445	-1892.267	-420.2241	-1630.486	-501.8844	430.653	2553.699	4331.314	5466.62	5762.543	5279.539	4123.523	2409.573	333.1852

so, maximum wave force applied on the hull is when t=12.7 sec.

APPENDIX C

Moment Calculation

MOMENT AT HARD TANK

Location of COG = 65 m from msl

S	Force, f_x (N)	At depth, y (m)	Moment arm (m)	Moment, M (Nm)
1324.5	333185.22	-0.5	65	21657039.46
1323.5	323707.24	-1.5	64	20717263.66
1322.5	314498.88	-2.5	63	19813429.62
1321.5	305552.47	-3.5	62	18944252.97
1320.5	296860.55	-4.5	61	18108493.35
1319.5	288415.88	-5.5	60	17304952.88
1318.5	280211.44	-6.5	59	16532474.84
1317.5	272240.38	-7.5	58	15789942.2
1316.5	264496.08	-8.5	57	15076276.37
1315.5	256972.07	-9.5	56	14390435.9
1314.5	249662.09	-10.5	55	13731415.22
1313.5	242560.06	-11.5	54	13098243.45
1312.5	235660.06	-12.5	53	12489983.24
1311.5	228956.34	-13.5	52	11905729.68
1310.5	222443.32	-14.5	51	11344609.15
1309.5	216115.57	-15.5	50	10805778.33
1308.5	209967.82	-16.5	49	10288423.15
1307.5	203994.95	-17.5	48	9791757.811
1306.5	198192.00	-18.5	47	9315023.858
1305.5	192554.11	-19.5	46	8857489.236
1304.5	187076.61	-20.5	45	8418447.411
1303.5	181754.92	-21.5	44	7997216.509
1302.5	176584.62	-22.5	43	7593138.488
1301.5	171561.39	-23.5	42	7205578.329
1300.5	166681.06	-24.5	41	6833923.262
1299.5	161939.55	-25.5	40	6477582.013
1298.5	157332.93	-26.5	39	6135984.077
1297.5	152857.34	-27.5	38	5808579.014
1296.5	148509.07	-28.5	37	5494835.771
1295.5	144284.50	-29.5	36	5194242.022
1294.5	140180.10	-30.5	35	4906303.535
1293.5	136192.46	-31.5	34	4630543.555
1292.5	132318.25	-32.5	33	4366502.21
1291.5	128554.25	-33.5	32	4113735.937
1290.5	124897.32	-34.5	31	3871816.926
1289.5	121344.42	-35.5	30	3640332.583
1288.5	117892.59	-36.5	29	3418885.009
1287.5	114538.95	-37.5	28	3207090.5
1286.5	111280.71	-38.5	27	3004579.059
1285.5	108115.15	-39.5	26	2810993.93
1284.5	105039.65	-40.5	25	2625991.14

1283.5	102051.63	-41.5	24	2449239.063
1282.5	99148.61	-42.5	23	2280417.996
1281.5	96328.17	-43.5	22	2119219.748
1280.5	93587.96	-44.5	21	1965347.244
1279.5	90925.71	-45.5	20	1818514.143
1278.5	88339.18	-46.5	19	1678444.465
1277.5	85826.24	-47.5	18	1544872.236
1276.5	83384.77	-48.5	17	1417541.142
1275.5	81012.76	-49.5	16	1296204.192
1274.5	78708.23	-50.5	15	1180623.398
1273.5	76469.25	-51.5	14	1070569.461
1272.5	74293.96	-52.5	13	965821.4689
1271.5	72180.55	-53.5	12	866166.6072
1270.5	70127.26	-54.5	11	771399.8741
1269.5	68132.38	-55.5	10	681323.8101
1268.5	66194.25	-56.5	9	595748.2342
1267.5	64311.25	-57.5	8	514489.9897
1266.5	62481.81	-58.5	7	437372.6985
1265.5	60704.42	-59.5	6	364226.5234
1264.5	58977.59	-60.5	5	294887.9391
1263.5	57299.88	-61.5	4	229199.5102
1262.5	55669.89	-62.5	3	167009.6772
1261.5	54086.27	-63.5	2	108172.5494
1260.5	52547.71	-64.5	1	52547.70554
1259.5	51052.90	-65.5	0	0
1258.5	49600.62	-66.5	-1	-49600.62323
1257.5	48189.66	-67.5	-2	-96379.31094
1256.5	46818.82	-68.5	-3	-140456.4747
1255.5	45486.99	-69.5	-4	-181947.9591
1254.5	44193.04	-70.5	-5	-220965.204
1253.5	42935.90	-71.5	-6	-257615.4013
1252.5	41714.52	-72.5	-7	-292001.6469

Total Moment, kN.M	**421349708.7**

APPENDIX D

P-M Wave Spectrum Calculation

P-M SPECTRUM

D	46
Hs	12.59
d	1325
Tp	14.5
t	0
ω_{02}	0.1254
ω_0	0.3541
f_0	0.0564
g	9.8067
α	0.0081
$\alpha g^2/(2\pi)^4$	0.0005

f	$(f)^{-5}$	$(f/f0)^{-4}$	S(f), m-s^2	(S(f)*Δf),m^2	H(f), m	R_d	ξ	2πf(N), rad/s	T, s	L(N), m	k(N)
0.005	320000000000	16145.1525	0.0000	0.0000	0.0000	0.2757	1.7325	0.0314	200.00	62452.3997	0.0001
0.015	1316872428	199.3229	0.0000	0.0000	0.0000	0.5766	3.6227	0.0942	66.67	6939.1555	0.0009
0.025	102400000	25.8322	0.0000	0.0000	0.0000	0.1109	0.6970	0.1571	40.00	2498.0960	0.0025
0.035	19039686	6.7243	2.1283	0.0213	0.4126	0.9401	5.9068	0.2199	28.57	1274.5388	0.0049
0.045	5419228	2.4608	124.9877	1.2499	3.1621	0.3548	2.2290	0.2827	22.22	771.0173	0.0081
0.055	1986948	1.1027	250.2381	2.5024	4.4743	0.8081	5.0772	0.3456	18.18	516.1355	0.0122
0.065	861853	0.5653	212.5025	2.1250	4.1231	0.6172	3.8777	0.4084	15.38	369.5408	0.0170
0.075	421399	0.3189	141.3745	1.4137	3.3630	0.6314	3.9675	0.4712	13.33	277.5662	0.0226
0.085	225375	0.1933	88.4652	0.8847	2.6603	0.2362	1.4842	0.5341	11.76	216.0983	0.0291
0.095	129236	0.1239	55.3266	0.5533	2.1038	0.4117	2.5867	0.5969	10.53	172.9983	0.0363
0.105	78353	0.0830	35.3015	0.3530	1.6805	0.3435	2.1584	0.6597	9.52	141.6154	0.0444
0.115	49718	0.0577	23.1205	0.2312	1.3600	0.4708	2.9582	0.7226	8.70	118.0575	0.0532
0.125	32768	0.0413	15.5532	0.1555	1.1155	0.7984	5.0162	0.7854	8.00	99.9238	0.0629
0.135	22301	0.0304	10.7311	0.1073	0.9265	0.3554	2.2328	0.8482	7.41	85.6686	0.0733
0.145	15601	0.0228	7.5784	0.0758	0.7786	0.0869	0.5458	0.9111	6.90	74.2597	0.0846
0.155	11177	0.0175	5.4659	0.0547	0.6613	0.1911	1.2008	0.9739	6.45	64.9869	0.0967
0.165	8177	0.0136	4.0179	0.0402	0.5669	0.3888	2.4431	1.0367	6.06	57.3484	0.1096
0.175	6093	0.0108	3.0045	0.0300	0.4903	0.2047	1.2859	1.0996	5.71	50.9816	0.1232
0.185	4615	0.0086	2.2818	0.0228	0.4272	0.9623	6.0462	1.1624	5.41	45.6190	0.1377
0.195	3547	0.0070	1.7573	0.0176	0.3749	0.3912	2.4579	1.2252	5.13	41.0601	0.1530
0.205	2762	0.0057	1.3707	0.0137	0.3311	0.9910	6.2268	1.2881	4.88	37.1519	0.1691
0.215	2177	0.0047	1.0816	0.0108	0.2942	0.4787	3.0075	1.3509	4.65	33.7763	0.1860
0.225	1734	0.0039	0.8625	0.0086	0.2627	0.6768	4.2528	1.4137	4.44	30.8407	0.2037
0.235	1395	0.0033	0.6945	0.0069	0.2357	0.5853	3.6777	1.4765	4.26	28.2718	0.2222
0.245	1133	0.0028	0.5642	0.0056	0.2125	0.7782	4.8894	1.5394	4.08	26.0110	0.2416
0.255	927	0.0024	0.4622	0.0046	0.1923	0.1597	1.0034	1.6022	3.92	24.0109	0.2617
0.265	765	0.0020	0.3815	0.0038	0.1747	0.0446	0.2801	1.6650	3.77	22.2330	0.2826
0.275	636	0.0018	0.3171	0.0032	0.1593	0.0428	0.2691	1.7279	3.64	20.6454	0.3043
0.285	532	0.0015	0.2653	0.0027	0.1457	0.3763	2.3644	1.7907	3.51	19.2220	0.3269
0.295	448	0.0013	0.2233	0.0022	0.1337	0.1098	0.6898	1.8535	3.39	17.9409	0.3502
0.305	379	0.0012	0.1891	0.0019	0.1230	0.4337	2.7249	1.9164	3.28	16.7838	0.3744
0.315	322	0.0010	0.1610	0.0016	0.1135	0.4011	2.5205	1.9792	3.17	15.7350	0.3993
0.325	276	0.0009	0.1377	0.0014	0.1050	0.3614	2.2706	2.0420	3.08	14.7816	0.4251
0.335	237	0.0008	0.1183	0.0012	0.0973	0.0365	0.2290	2.1049	2.99	13.9123	0.4516
0.345	205	0.0007	0.1022	0.0010	0.0904	0.1275	0.8008	2.1677	2.90	13.1175	0.4790
0.355	177	0.0006	0.0886	0.0009	0.0842	0.9550	6.0002	2.2305	2.82	12.3889	0.5072
0.365	154	0.0006	0.0771	0.0008	0.0785	0.7707	4.8423	2.2934	2.74	11.7193	0.5361
0.375	135	0.0005	0.0674	0.0007	0.0734	0.4659	2.9273	2.3562	2.67	11.1026	0.5659
0.385	118	0.0005	0.0591	0.0006	0.0687	0.8651	5.4355	2.4190	2.60	10.5334	0.5965
0.395	104	0.0004	0.0520	0.0005	0.0645	0.0183	0.1151	2.4819	2.53	10.0068	0.6279
			Total Area, m_0	9.9111							

H(n)	0	0.566948	0.490267	0.427249	0.374945	0.331141	0.294151	0.262678	0.235711	0.212458	0.192287	0.174694	0.159271	0.145687	0.133669	0.122994	0.064468	
f(n)	0.005	0.165	0.175	0.185	0.195	0.205	0.215	0.225	0.235	0.245	0.255	0.265	0.275	0.285	0.295	0.305	0.395	
ξ(n)	1.732546	2.443121	1.285946	6.046188	2.457863	6.226816	3.007544	4.25277	3.677688	4.889363	1.003446	0.280082	0.269131	2.364431	0.689825	2.724886	0.115077	
t	η= (H(n)/2)*COS(-2*PI()*f(n)*t+ξ(n))																	sum
0	0	-0.21709	0.068886	0.207653	-0.14533	0.165308	-0.14576	-0.05826	-0.10132	0.018702	0.051668	0.083943	0.076769	-0.05193	0.051553	-0.05623	0.032021	-4.21212
1	0	0.046394	0.240888	0.036438	0.062193	0.037162	-0.01261	-0.12537	-0.06947	-0.10393	0.079418	0.016139	0.008905	0.06118	0.026462	0.042468	-0.02303	-3.04735
2	0	0.264324	0.149836	-0.17871	0.187467	-0.14457	0.140253	0.019037	0.088247	-0.02523	-0.05666	-0.08698	-0.07955	0.025239	-0.06632	0.027463	0.004378	-1.97336
3	0	0.22271	-0.10484	-0.17839	0.064811	-0.11783	0.073803	0.13133	0.086076	0.102346	-0.07586	0.000232	0.015986	-0.07219	0.010543	-0.06107	0.016114	-1.08265
4	0	-0.03759	-0.24503	0.037018	-0.14356	0.078825	-0.10805	0.022052	-0.07205	0.03166	0.061422	0.086937	0.074554	0.006258	0.060436	0.013913	-0.02984	-0.51644
5	0	-0.26098	-0.11764	0.20779	-0.16207	0.161813	-0.12095	-0.12443	-0.09964	-0.10036	0.072	-0.0166	-0.03931	0.069461	-0.04426	0.051648	0.031048	-0.29273
6	0	-0.22811	0.138213	0.128029	0.033761	0.011464	0.055287	-0.06098	0.053293	-0.03796	-0.06595	-0.08381	-0.06225	-0.03656	-0.03574	-0.0489	-0.01922	0.267392
7	0	0.028743	0.243135	-0.1061	0.184942	-0.15542	0.145067	0.105351	0.109667	0.097972	-0.06786	0.032371	0.058789	-0.05351	0.064206	-0.01852	-0.00067	1.444365
8	0	0.257372	0.08255	-0.2123	0.091532	-0.09818	0.008004	0.093944	-0.03265	0.04412	0.070208	0.077721	0.043861	0.059908	-8.9E-05	0.061448	0.020283	1.289923
9	0	0.233283	-0.16818	-0.06253	-0.12293	0.100632	-0.14157	-0.07596	-0.11581	-0.0952	0.063446	-0.047	-0.07251	0.027372	-0.06416	-0.02311	-0.03138	0.109195
10	0	-0.01987	-0.23526	0.162632	-0.17481	0.154334	-0.06977	-0.11771	0.010854	-0.0501	-0.07419	-0.06887	-0.02117	-0.07185	0.035887	-0.04579	0.02931	0.659834
11	0	-0.25351	-0.04543	0.191711	0.004498	-0.01452	0.111135	0.039132	0.117855	0.092053	-0.05879	0.059962	0.079136	0.003975	0.044132	0.054134	-0.01494	2.635294
12	0	-0.23823	0.19401	-0.01036	0.177862	-0.16243	0.118258	0.129952	0.011329	0.055883	0.077887	0.057589	-0.00358	0.070116	-0.06051	0.009116	-0.0057	3.894108
13	0	0.010978	0.221583	-0.19994	0.115999	-0.07612	-0.05954	0.001526	-0.11572	-0.08854	0.053892	-0.0708	-0.07801	-0.03457	-0.01037	-0.06031	0.023952	3.840459
14	0	0.249403	0.007183	-0.14845	-0.09928	0.119961	-0.14423	-0.12947	-0.03311	-0.06145	-0.08127	-0.04426	0.027993	-0.05504	0.066296	0.031743	-0.03215	3.40507
15	0	0.242935	-0.21506	0.082022	-0.18326	0.143055	-0.00339	-0.04203	0.109491	0.084682	-0.04879	0.079133	0.069257	0.058577	-0.02662	0.038805	0.02685	2.077951
16	0	-0.00208	-0.20245	0.213602	-0.02488	-0.04014	0.142757	0.116323	0.053718	0.066765	0.084337	0.029369	-0.04966	0.029479	-0.05144	-0.05803	-0.01028	-1.17019
17	0	-0.24505	0.031236	0.087641	0.166403	-0.16545	0.06567	0.078429	-0.09938	-0.08049	0.043489	-0.08466	-0.05372	-0.07144	0.055327	0.00051	-0.0106	-4.43631
18	0	-0.2474	0.230816	-0.14399	0.13761	-0.05218	-0.11411	-0.09179	-0.07242	-0.07182	-0.08707	-0.01343	0.066468	0.001688	0.020569	0.057686	0.027032	-6.07832
19	0	-0.00683	0.178341	-0.20201	-0.07318	0.136336	-0.11545	-0.10715	0.08575	0.075976	-0.03802	0.087189	0.032923	0.070702	-0.0668	-0.03959	-0.03212	-5.61335
20	0	0.240451	-0.06889	-0.01647	-0.18718	0.128254	0.063735	0.058263	0.088562	0.076595	0.089458	-0.00298	-0.07677	-0.03253	0.016707	-0.03086	0.02373	-3.30491
21	0	0.251628	-0.24089	0.188931	-0.05364	-0.06477	0.143259	0.125374	-0.06908	-0.07116	0.032399	-0.08663	-0.0089	-0.05651	0.057482	0.060501	-0.00538	-1.31635
22	0	0.015728	-0.14984	0.166535	0.150847	-0.1644	-0.00123	-0.01904	-0.10156	-0.08107	-0.09149	0.019281	0.079555	0.057188	-0.04878	-0.01012	-0.01523	0.060446
23	0	-0.23562	0.10484	-0.05665	0.155833	-0.02696	-0.1438	-0.13133	0.049965	0.066071	-0.02665	0.083	-0.01599	0.031557	-0.03026	-0.05364	0.029446	1.32103
24	0	-0.2556	0.245028	-0.21153	-0.04527	0.149354	-0.0615	-0.02205	0.110969	0.085216	0.093167	-0.0349	-0.07455	-0.07096	0.065667	0.046465	-0.0313	1.675193
25	0	-0.02461	0.117641	-0.11137	-0.1865	0.110294	0.116964	0.124431	-0.02908	-0.06072	0.020798	-0.07643	0.039311	-0.0006	-0.00638	0.022163	0.020025	1.481106
26	0	0.230549	-0.13821	0.123076	-0.08108	-0.08781	0.112534	0.060982	-0.11644	-0.08903	-0.09447	0.049288	0.062254	0.071218	-0.06211	-0.06148	-0.00034	1.136005
27	0	0.259328	-0.24314	0.209126	0.131576	-0.15929	-0.06787	-0.10535	0.007162	0.055125	-0.01486	0.067154	-0.05879	-0.03047	0.041033	0.019488	-0.01949	0.80412
28	0	0.033469	-0.08255	0.043032	0.170218	-0.00107	-0.14214	-0.09394	0.11779	0.092493	0.095408	-0.06193	-0.04386	-0.05792	0.039213	0.048277	0.031135	0.483121
29	0	-0.22525	0.168182	-0.17495	-0.01626	0.158694	0.005852	0.075959	0.015008	-0.04931	0.008869	-0.0555	0.072511	0.055743	-0.06291	-0.0522	-0.02972	0.047376
30	0	-0.2628	0.235256	-0.18199	-0.18123	0.089619	0.144696	0.117709	-0.11497	-0.09559	-0.09596	0.072373	0.021175	0.033604	-0.00411	-0.01292	0.015827	0.043144

APPENDIX E

RAO Calculation

REGULAR WAVE CONDITION

SURGE

Mass of structure , N	1.25E+08
added mass N , $m_{a11,}$	1.25E+08
total mass, m11, MN	2.50E+08
Natural Period, t_n	200
Natural frequency, $\omega_{n,}$	0.031415927
stiffness, $k_{s,}$N/m	2.47E+05
Cc	1.57E+07
C	7.85E+05
ω	0.376238641
t	16.7
Fx, N	261935508.8
(Fx/(H/2))	21827959.07
$((k-m\omega^2)^2$	1.23497E+15
(cω)2)	87318558423
Lower	35143381
RAO	0.621111528

HEAVE

Total Fy	86022538.39
ρ	1030
g	9.8067
D	46
added mass	2.62E+07
struct. Mass	1.25E+08
total M	1.51E+08
ωn	0.334211984
Kh	1.69E+07
Cc	1.01E+08
C	5.05E+06
ω	0.376238641
(k-mw^2)^2	2.03935E+13
(cw^2)	1.44679E+15
upper	7168544.866
lower	38303776.57
RAO	0.187149819

PITCH

Total Moment, Nm	9244283589
ρ	1030
g	9.8067
D	46
added mass MI, kg-m^2	3.72E+10
struct. Mass MI, kg-m^2	3.72E+10
total MI, kg-m^2	7.44E+10
ωn	0.104719755
K, N.m/radian	8.16E+08
Cc	1.56E+10
C	7.79E+08
ω	0.376238641
(k-mw^2)^2	9.43738E+19
(cw^2)	3.43622E+19
upper	770356965.7
lower	11346187729
RAO	0.067895665

APPENDIX F

Surge Motion Response

SURGE DATA FOR HOLSTEIN TRUSS SPAR

SURGE RESPONSE DATA

Mass of structure , N	1.25E+08
added mass N , $m_{a11,}$	1.25E+08
total mass, m11, MN	2.50E+08
Natural Period, t_n	200
Natural frequency, $\omega_{n,}$	0.031415927
stiffness, $k_{s,}$N/m	2.47E+05
Cc	1.57E+07
C	7.85E+05
ω	0.376238641
t	16.7
Fx, N	261935508.8
(Fx/(H/2))	21827959.07
$((k-m\omega^2)^2$	1.23497E+15
(cω)2)	87318558423
Lower	35143381
RAO	0.621111528

f, sp	H(f), sp	ω, Sp	Fx, MN	lower	S(f), m-s^2	RAO $_{surge}$	S_x(f), m-s^2	S(f_x)*Δf), m^2	H_f surge, m	Rd	ξ(n)
0.005	0	0.0314159	0	24674.011	0	0.000	0	0	0	0.0938817	0.589876
0.015	1.81011E-52	0.0942478	0	1975308.3	2.19213E-97	0.000	0	0	0	0.2211632	1.3896094
0.025	6.22799E-06	0.1570796	0	5923047.6	2.67932E-09	0.000	0	0	0	0.4947584	3.1086588
0.035	0.41263124	0.2199115	5315694.67	11844785	3.321177427	0.090	0.026755791	0.000267558	0.046265141	0.2890035	1.8158624
0.045	3.162122638	0.2827433	41591835.3	19740458	147.0923897	0.421	26.11872182	0.261187218	1.445509511	0.0034526	0.0216932
0.055	4.474265132	0.3455752	70738931.4	29610057	269.1820494	0.478	61.45321172	0.614532117	2.217263389	0.0565504	0.3553166
0.065	4.123129731	0.408407	83905460.8	41453580	220.6024677	0.405	36.15153449	0.361515345	1.700624226	0.178965	1.1244701
0.075	3.363027824	0.4712389	86247281.9	55271024	144.38983	0.312	14.06346743	0.140634674	1.060696655	0.7173909	4.5074997
0.085	2.660303342	0.5340708	86658130.2	71062390	89.60411752	0.244	5.329997086	0.053299971	0.65299293	0.5332635	3.3505932
0.095	2.103837163	0.5969026	94649580	88827677	55.78209103	0.213	2.533352113	0.025333521	0.450186816	0.6100779	3.8332326
0.105	1.680512164	0.6597345	76204087.7	108566885	35.4959851	0.140	0.699521403	0.006995214	0.23656228	0.2728358	1.7142781
0.115	1.360015065	0.7225663	72737888.6	130280014	23.20895459	0.112	0.289388559	0.002893886	0.152154805	0.9737061	6.117976
0.125	1.115461559	0.7853982	69031254.3	153967064	15.59578001	0.090	0.125401567	0.001254016	0.100160498	0.7588528	4.7680127
0.135	0.92654788	0.84823	63965821.9	179628035	10.75273313	0.071	0.054541438	0.000545414	0.066055394	0.6779683	4.2598004
0.145	0.778632258	0.9110619	58281101.4	207262928	7.589809022	0.056	0.024005076	0.000240051	0.043822438	0.2915489	1.8318555
0.155	0.661262569	0.9738937	52855025.9	236871741	5.472179446	0.045	0.010898492	0.000108985	0.029527603	0.3788941	2.3806621
0.165	0.566948059	1.0367256	46947227.3	268454475	4.021497708	0.035	0.004919562	4.91956E-05	0.019838471	0.4858158	3.0524706
0.175	0.490267353	1.0995574	43620820	302011129	3.006665912	0.029	0.002508921	2.50892E-05	0.014167344	0.4926636	3.0954967
0.185	0.427248773	1.1623893	41901122.5	337541705	2.283070095	0.025	0.001407264	1.40726E-05	0.010610426	0.8240908	5.1779154
0.195	0.374945043	1.2252211	27447393	375046202	1.758109085	0.015	0.00037665	3.7665E-06	0.005489265	0.9791146	6.1519583
0.205	0.331140984	1.288053	37158899.2	414524619	1.371197744	0.018	0.000440743	4.40743E-06	0.005937964	0.4322256	2.7157538
0.215	0.294151086	1.3508848	34458214.3	455976958	1.081898821	0.015	0.000247142	2.47142E-06	0.004446499	0.3898821	2.4497014
0.225	0.262677845	1.4137167	33386045.5	499403217	0.862720384	0.013	0.000154226	1.54226E-06	0.003512559	0.9272031	5.8257891
0.235	0.235711464	1.4765485	31671703.8	544803397	0.694650761	0.012	9.39052E-05	9.39052E-07	0.002740879	0.4664528	2.9308093
0.245	0.212457977	1.5393804	28915267.3	592177498	0.564334479	0.010	5.38204E-05	5.38204E-07	0.002075002	0.5245028	3.2955481

Hf surge, m	0	1.700624226	1.060696655	0.65299293	0.450186816	0.23656228	0.15215481	0.1	0.066055394	0.043822438	0.029527603	0.005937964	0.0044465	0.003512559	0.002740879	0	
f, (n)	0.01	0.065	0.075	0.085	0.095	0.105	0.115	0.1	0.135	0.145	0.155	0.205	0.215	0.225	0.235	0.25	
ξ(n)	0.59	1.12447012	4.507499669	3.350593196	3.833232641	1.714278118	6.117976	4.8	4.259800392	1.831855457	2.380662148	2.715753751	2.4497014	5.825789125	2.930809272	3.3	
t	η= (H(n)/2)*COS(-2*PI()*f(n)*t+ξ(n)																sum
1	0	0.641471924	-0.33188017	-0.30939729	-0.22408404	0.058386486	0.04801541	-0	-0.031831329	0.01326042	0.002410831	0.0004234	0.0010108	-0.00051955	0.000159344	-0	1.630099
2	0	0.810386559	-0.48351076	-0.213231	-0.19730393	0.109181768	-0.00300774	-0	-0.027658026	0.021910181	0.013402042	0.002940079	0.00215299	-0.00173829	0.001370099	0	1.658124
3	0	0.846000102	-0.52974232	-0.05767648	-0.10228845	0.114154556	-0.0525277	-0	-0.004749832	0.01359739	0.012655299	0.001217112	-7.148E-05	-2.4311E-05	9.85317E-05	0	1.57761
4	0	0.742454455	-0.46049696	0.113941863	0.028102344	0.071217822	-0.07579547	-0	0.021375785	-0.005242309	0.000824625	-0.00226095	-0.0021842	0.001730688	-0.001351554	-0	1.349573
5	0	0.516781919	-0.29086928	0.25382558	0.148774256	-0.001608319	-0.06118235	0	0.033021953	-0.020023486	-0.011728283	-0.00247868	-0.0008814	0.000565789	-0.000352917	-0	0.957732
6	0	0.206103538	-0.05783588	0.323014825	0.217994251	-0.073759464	-0.01599164	0.1	0.022299834	-0.019302763	-0.014009171	0.000877891	0.00179961	-0.00155367	0.001285129	0	0.407744
7	0	-0.13847697	0.187804976	0.302239291	0.211823364	-0.114954502	0.03719133	0	-0.003527664	-0.003638113	-0.004020361	0.002968531	0.00166659	-0.00105188	0.000594799	0	-0.271498
8	0	-0.46027929	0.392506801	0.197285295	0.132395729	-0.107904287	0.0717869	0	-0.026965606	0.014843113	0.009489615	0.000778496	-0.0010725	0.001224568	-0.001173178	-0	-1.019519
9	0	-0.70636993	0.511647266	0.037384198	0.007180506	-0.055567725	0.07050497	-0	-0.032137686	0.02183301	0.014688271	-0.00253414	-0.0021345	0.001435014	-0.000815611	-0	-1.74208
10	0	-0.83626926	0.519255303	-0.13292899	-0.12051801	0.020090054	0.03398621	-0	-0.01554046	0.011920099	0.007022451	-0.0021925	0.00014124	-0.0007756	0.001019666	0	-2.319779
11	0	-0.82861002	0.413672459	-0.26621934	-0.20653672	0.087316239	-0.0195181	-0	0.011583504	-0.007221185	-0.006793865	0.001310766	0.00219613	-0.00167767	0.001007529	0	-2.625176
12	0	-0.6846521	0.217914417	-0.32536336	-0.22112701	0.117896674	-0.0632677	-0	0.030861078	-0.020771929	-0.014659888	0.002923887	0.0008169	0.000250705	-0.000830033	-0	-2.555726
13	0	-0.42807525	-0.02534612	-0.29388849	-0.15924298	0.098997057	-0.0753975	0	0.02923409	-0.018241339	-0.009686294	0.000320711	-0.0018397	0.001756111	-0.001163755	-0	-2.082292
14	0	-0.10108398	-0.26308154	-0.18056099	-0.04228655	0.038549367	-0.0498453	0.1	0.007804623	-0.001588561	0.003770879	-0.00274494	-0.0016196	0.000298728	0.000610995	0	-1.280511
15	0	0.242534676	-0.44346862	-0.01694438	0.089294219	-0.038077105	0.00061848	0	-0.01891151	0.016294058	0.01392539	-0.00185234	0.00113314	-0.00166265	0.001278754	0	-0.307348
16	0	0.546258617	-0.52718532	0.151391515	0.189993576	-0.098722998	0.05077315	0	-0.032817435	0.021562047	0.011883582	0.001711365	0.00211393	-0.00081892	-0.000370312	-0	0.665899
17	0	0.760128069	-0.4959825	0.277562457	0.224985773	-0.117935838	0.07555253	-0	-0.024493608	0.010137004	-0.000566262	0.002807248	-0.0002109	0.001406434	-0.001348453	-0	1.508228
18	0	0.848963487	-0.35666197	0.326427829	0.182169148	-0.08765219	0.06257243	-0	0.000421607	-0.009135965	-0.012520155	-0.00014497	-0.0022059	0.001258949	0.000116511	0	2.134648
19	0	0.798152264	-0.13959378	0.284377845	0.076351355	-0.020581796	0.01832001	-0	0.025051237	-0.021335999	-0.01350848	-0.00288814	-0.0007515	-0.00101255	0.001370382	0	2.482369
20	0	0.616052379	0.107904028	0.163124097	-0.0558717	0.055126572	-0.03508834	-0	0.032711752	-0.017018003	-0.002665629	-0.00146656	0.00187803	-0.00157574	0.000141418	-0	2.50022
21	0	0.332617576	0.331880167	-0.00356231	-0.16877216	0.10769887	-0.07096032	0	0.018214104	0.00047509	0.010511869	0.002069825	0.00157091	0.000519547	-0.001343765	-0	2.169229
22	0	-0.00552974	0.483510761	-0.16925656	-0.22330464	0.115071032	-0.0713679	0.1	-0.008621347	0.017600375	0.014482722	0.002621485	-0.0011927	0.001738294	-0.000394337	0	1.536109
23	0	-0.34276747	0.529742317	-0.28781016	-0.2006097	0.074149035	-0.03610738	0	-0.029616901	0.021099698	0.005769126	-0.00060708	-0.0020913	2.43109E-05	0.001269544	0	0.724209
24	0	-0.62362311	0.460496961	-0.32620404	-0.10853614	0.002107432	0.01719881	0	-0.03055067	0.008263932	-0.007997262	-0.00296023	0.00028028	-0.00173069	0.000633287	-0	-0.101706
25	0	-0.80189853	0.290869276	-0.27374489	0.021073441	-0.070818639	0.06190941	-0	-0.010790139	-0.010969653	-0.014759382	-0.00104467	0.00221354	-0.00056579	-0.001150349	-0	-0.801229
26	0	-0.84826906	0.057835884	-0.14504343	0.143395005	-0.114022838	0.07567906	-0	0.016279375	-0.021710688	-0.008594745	0.002377319	0.00068546	0.00155367	-0.000849801	0	-1.303732
27	0	-0.75510717	-0.18780498	0.024054947	0.216125006	-0.109372794	0.05162599	-0	0.032321628	-0.015643615	0.005097456	0.002371173	-0.0019145	0.001051884	0.000990403	0	-1.598652
28	0	-0.53773714	-0.3925068	0.186453633	0.214110582	-0.058820085	0.0017714	-0	0.026469976	0.002534525	0.014325135	-0.00105425	-0.0015207	-0.00122457	0.001036212	-0	-1.695545
29	0	-0.23191433	-0.51164727	0.296922009	0.138048401	0.016418824	-0.0489685	0	0.002688191	0.018750471	0.011006385	-0.00295942	0.00125101	-0.00143501	-0.00079537	-0	-1.605619
30	0	0.11205625	-0.5192553	0.324692871	0.014243719	0.084766917	-0.07523503	0.1	-0.022914511	0.020450067	-0.001952123	-0.00059706	0.00206652	0.000775597	-0.001185914	0	-1.353263
31	0	0.437594609	-0.41367246	0.262031591	-0.11448699	0.117539185	-0.06390076	0	-0.032995467	0.00631751	-0.013200897	0.002626275	-0.0003494	0.001677674	0.000572162	0	-0.980445
32	0	0.691152703	-0.21791442	0.126390334	-0.20362366	0.100981435	-0.0206303	0	-0.020726077	-0.012705974	-0.012887886	0.002062474	-0.002219	-0.0002507	0.001293604	-0	-0.528728
33	0	0.831022572	0.025346125	-0.04445265	-0.22233935	0.042042789	0.03295073	-0	0.005582666	-0.021892672	-0.001287236	-0.00147545	-0.0006187	-0.00175611	-0.000328684	-0	-0.030722
34	0	0.834196916	0.263081542	-0.20291486	-0.16416145	-0.034540794	0.07006371	-0	0.028109843	-0.014130372	0.011440818	-0.00288575	0.00194904	-0.00029873	-0.001355468	0	0.468775
35	0	0.700153584	0.443468616	-0.30486204	-0.04921015	-0.096627952	0.0721604	-0	0.03159608	0.004571463	0.014148624	-0.00013475	0.00146903	0.001662649	7.35624E-05	0	0.894744
36	0	0.450941465	0.527185318	-0.32190029	0.082759933	-0.118161327	0.03819292	-0	0.013679882	0.019734136	0.004464594	0.002810564	-0.0013081	0.000818919	0.001369313	-0	1.164002
37	0	0.127553647	0.4959825	-0.24928417	0.186108417	-0.090103578	-0.01486254	0	-0.013502744	0.019618919	-0.009129675	0.00170299	-0.0020397	-0.00140643	0.000184165	-0	1.228764
38	0	-0.21681557	0.356661968	-0.10723844	0.225093381	-0.024230261	-0.06049002	0.1	-0.031538931	0.004315012	-0.014727872	-0.00186033	0.00041821	-0.00125895	-0.00133465	0	1.093918
39	0	-0.52552062	0.139593782	0.06467491	0.186232308	0.051812254	-0.07588594	0	-0.028211395	-0.014329516	-0.007426908	-0.00274102	0.0022222	0.001012548	-0.000435369	0	0.798583
40	0	-0.7477824	-0.10790403	0.218575265	0.082964868	0.106109686	-0.05335574	0	-0.005774129	-0.021880336	0.006378788	0.000330886	0.0005513	0.001575744	0.001252707	-0	0.39463
41	0	-0.84704089	-0.33188017	0.311598923	-0.04899505	0.115873946	-0.00415952	-0	0.020574394	-0.012491708	0.01459773	0.002925647	-0.0019817	-0.00051955	0.000671149	-0	-0.05679
42	0	-0.80696899	-0.48351076	0.317837312	-0.16401057	0.077007072	0.04711553	-0	0.032986312	0.006567824	0.010031495	0.001301573	-0.0014159	-0.00173829	-0.001126385	0	-0.48259
43	0	-0.63415816	-0.52974232	0.235552942	-0.22230487	0.005821103	0.07484328	-0	0.023054084	0.020542639	-0.003320657	-0.00219939	0.00136395	-2.4311E-05	-0.000883153	0	-0.803372
44	0	-0.35703417	-0.46049696	0.087663321	-0.2037175	-0.067807925	0.06516602	-0	-0.002494433	0.018613633	-0.013764467	-0.0025288	0.00201095	0.001730688	0.000960161	-0	-0.945727

APPENDIX G

Heave Motion Response

HEAVE RESPONSE DATA

Total Fy	86022538.39
ρ	1030
g	9.8067
D	46
added mass	2.62E+07
struct. Mass	1.25E+08
total M	1.51E+08
ωn	0.334211984
Kh	1.69E+07
Cc	1.01E+08
C	5.05E+06
ω	0.376238641
(k-mw^2)^2	2.03935E+13
(cw^2)	1.44679E+15
upper	7168544.866
lower	38303776.57
RAO	0.187149819

f	H(f), sp	ω, Sp	Fy, N	S(f), m-s^2	RAO_{heave}	S_y(f), m-s^2	S(f_y)*Δf), m^2	H_f heave, m	Rd	ξ(n)	ω(N), rad/s	T, s
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.5486	3.4469	0.0000	#DIV/0!
0.0150	0.0000	0.0942	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3274	2.0569	0.0942	66.6667
0.0250	0.0000	0.1571	57986.8127	0.0000	0.0003	0.0000	0.0000	0.0000	0.5662	3.5574	0.1571	40.0000
0.0350	0.4126	0.2199	3189324.3291	2.1283	0.0167	0.0006	0.0000	0.0069	0.7543	4.7395	0.2199	28.5714
0.0450	3.1621	0.2827	18221879.8002	124.9877	0.0951	1.1314	0.0113	0.3009	0.2333	1.4659	0.2827	22.2222
0.0550	4.4743	0.3456	19009636.9428	250.2381	0.0993	2.4653	0.0247	0.4441	0.1456	0.9146	0.3456	18.1818
0.0650	4.1231	0.4084	13155604.7375	212.5025	0.0687	1.0027	0.0100	0.2832	0.1463	0.9190	0.4084	15.3846
0.0750	3.3630	0.4712	6903906.5586	141.3745	0.0360	0.1837	0.0018	0.1212	0.7851	4.9329	0.4712	13.3333
0.0850	2.6603	0.5341	3431437.1685	88.4652	0.0179	0.0284	0.0003	0.0477	0.7624	4.7904	0.5341	11.7647
0.0950	2.1038	0.5969	1462502.2999	55.3266	0.0076	0.0032	0.0000	0.0161	0.5898	3.7061	0.5969	10.5263
0.1050	1.6805	0.6597	623775.5268	35.3015	0.0033	0.0004	0.0000	0.0055	0.7981	5.0144	0.6597	9.5238
0.1150	1.3600	0.7226	254731.4121	23.1205	0.0013	0.0000	0.0000	0.0018	0.7028	4.4161	0.7226	8.6957
0.1250	1.1155	0.7854	93133.6154	15.5532	0.0005	0.0000	0.0000	0.0005	0.9421	5.9193	0.7854	8.0000
0.1350	0.9265	0.8482	32576.8662	10.7311	0.0002	0.0000	0.0000	0.0002	0.8667	5.4457	0.8482	7.4074
0.1450	0.7786	0.9111	11461.8486	7.5784	0.0001	0.0000	0.0000	0.0000	0.5969	3.7504	0.9111	6.8966
0.1550	0.6613	0.9739	3822.1820	5.4659	0.0000	0.0000	0.0000	0.0000	0.0497	0.3125	0.9739	6.4516
0.1650	0.5669	1.0367	999.9473	4.0179	0.0000	0.0000	0.0000	0.0000	0.3805	2.3907	1.0367	6.0606
0.1750	0.4903	1.0996	234.3551	3.0045	0.0000	0.0000	0.0000	0.0000	0.7505	4.7156	1.0996	5.7143
0.1850	0.4272	1.1624	59.0456	2.2818	0.0000	0.0000	0.0000	0.0000	0.4318	2.7130	1.1624	5.4054
0.1950	0.3749	1.2252	11.2536	1.7573	0.0000	0.0000	0.0000	0.0000	0.7000	4.3981	1.2252	5.1282
0.2050	0.3311	1.2881	3.9580	1.3707	0.0000	0.0000	0.0000	0.0000	0.3025	1.9004	1.2881	4.8780
0.2150	0.2942	1.3509	0.7042	1.0816	0.0000	0.0000	0.0000	0.0000	0.7632	4.7956	1.3509	4.6512
0.2250	0.2627	1.4137	0.1625	0.8625	0.0000	0.0000	0.0000	0.0000	0.9973	6.2659	1.4137	4.4444
0.2350	0.2357	1.4765	0.0559	0.6945	0.0000	0.0000	0.0000	0.0000	0.4578	2.8764	1.4765	4.2553
0.2450	0.2125	1.5394	0.0114	0.5642	0.0000	0.0000	0.0000	0.0000	0.5421	3.4062	1.5394	4.0816

Hf surge, m	0	1.8173E-105	0.005473415	0.0018089	0	0.000157603	4.65989E-05	1.3197E-05	2.96012E-06	5.99923E-07	1.31722E-07	0	
f	0	0.015	0.105	0.115	0.1	0.135	0.145	0.155	0.165	0.175	0.185	0.25	
ξ(n)	3.447	2.056858469	5.014372977	4.416069332	5.9	5.445669801	3.750431767	0.312525469	2.390690389	4.715558681	2.712987869	3.41	
t	η= (H(n)/2)*COS(-2*PI()*f(n)*t+ξ(n))												sum
1	0	-3.4698E-106	-0.000958307	-0.000770161	0	-9.03826E-06	-2.22434E-05	5.20721E-06	3.18414E-07	-2.66835E-07	1.33015E-09	-0	**0.331606**
2	0	-2.6641E-106	-0.002328361	-0.000891312	-0	-6.4697E-05	-8.15351E-06	-4.25081E-07	1.4062E-06	-2.43232E-07	6.096E-08	0	**0.379616**
3	0	-1.8348E-106	-0.002721224	-0.000567004	-0	-7.65316E-05	1.22488E-05	-5.68507E-06	1.11322E-06	4.5985E-08	4.70901E-08	0	**0.389553**
4	0	-9.8912E-107	-0.001972017	4.06795E-05	-0	-3.65255E-05	2.31682E-05	-5.96588E-06	-2.72856E-07	2.84985E-07	-2.35565E-08	-0	**0.363047**
5	0	-1.3469E-107	-0.000395175	0.000628032	-0	2.82222E-05	1.61512E-05	-1.02158E-06	-1.39101E-06	2.12776E-07	-6.58009E-08	-0	**0.303648**
6	0	7.2094E-107	0.001347519	0.000901509	0	7.38527E-05	-3.36989E-06	4.81746E-06	-1.1433E-06	-9.17885E-08	-2.87089E-08	0	**0.216767**
7	0	1.5702E-106	0.002524673	0.000724431	0	6.94572E-05	-2.0282E-05	6.4372E-06	2.27029E-07	-2.96118E-07	4.29976E-08	0	**0.10994**
8	0	2.4055E-106	0.002642246	0.000185298	0	1.8013E-05	-2.14921E-05	2.41903E-06	1.37444E-06	-1.77081E-07	6.28617E-08	-0	**-0.006998**
9	0	3.2194E-106	0.001650896	-0.000446442	0	-4.56328E-05	-6.06329E-06	-3.71781E-06	1.17226E-06	1.35332E-07	6.9332E-09	-0	**-0.122246**
10	0	4.0048E-106	-3.33193E-05	-0.000855061	-0	-7.8368E-05	1.40596E-05	-6.59847E-06	-1.80977E-07	2.9996E-07	-5.73547E-08	0	**-0.223083**
11	0	4.7546E-106	-0.00170355	-0.000836339	-0	-5.80186E-05	2.32978E-05	-3.69997E-06	-1.35651E-06	1.37026E-07	-5.24898E-08	0	**-0.297549**
12	0	5.4622E-106	-0.002658819	-0.000399634	-0	1.63119E-06	1.44991E-05	2.43908E-06	-1.20007E-06	-1.75543E-07	1.56623E-08	-0	**-0.336394**
13	0	6.1213E-106	-0.002498207	0.0002368	-0	6.01761E-05	-5.52455E-06	6.44191E-06	1.34747E-07	-2.96416E-07	6.49303E-08	-0	**-0.33481**
14	0	6.7261E-106	-0.001289123	0.000754886	0	7.79591E-05	-2.12712E-05	4.8027E-06	1.33725E-06	-9.3597E-08	3.59116E-08	0	**-0.293452**
15	0	7.2712E-106	0.000460993	0.000895697	0	4.29345E-05	-2.055E-05	-1.04288E-06	1.22668E-06	2.11432E-07	-3.64059E-08	0	**-0.218506**
16	0	7.7518E-106	0.002017635	0.000588858	0	-2.11729E-05	-3.91926E-06	-5.97506E-06	-8.83836E-08	2.85573E-07	-6.48286E-08	-0	**-0.12075**
17	0	8.1635E-106	0.002727496	-1.22787E-05	0	-7.09383E-05	1.57457E-05	-5.67409E-06	-1.31667E-06	4.78632E-08	-1.50872E-08	-0	**-0.01386**
18	0	8.5028E-106	0.002292654	-0.000607279	-0	-7.26518E-05	2.32206E-05	-4.03562E-07	-1.25209E-06	-2.42114E-07	5.28449E-08	0	**0.087708**
19	0	8.7666E-106	0.000895608	-0.000898775	-0	-2.51526E-05	1.27184E-05	5.22042E-06	4.19333E-08	-2.67698E-07	5.70617E-08	0	**0.170834**
20	0	8.9526E-106	-0.000877315	-0.000741083	-0	3.93843E-05	-7.63018E-06	6.27218E-06	1.29478E-06	-9.50787E-10	-7.52103E-09	-0	**0.225548**
21	0	9.0592E-106	-0.002282038	-0.000213014	-0	7.72433E-05	-2.20716E-05	1.83056E-06	1.27626E-06	2.66835E-07	-6.30356E-08	-0	**0.246287**
22	0	9.0853E-106	-0.002729013	0.000421514	0	6.27795E-05	-1.94255E-05	-4.21433E-06	4.55853E-09	2.43232E-07	-4.25479E-08	0	**0.232495**
23	0	9.0308E-106	-0.002030648	0.000845379	0	5.79035E-06	-1.74044E-06	-6.56817E-06	-1.27162E-06	-4.5985E-08	2.924E-08	0	**0.188526**
24	0	8.8961E-106	-0.000480041	0.000846742	0	-5.5121E-05	1.7292E-05	-3.16939E-06	-1.29917E-06	-2.84985E-07	6.57731E-08	-0	**0.122886**
25	0	8.6825E-106	0.001272035	0.000424922	0	-7.86947E-05	2.29372E-05	3.00525E-06	-5.10458E-08	-2.12776E-07	2.30033E-08	-0	**0.046905**
26	0	8.3918E-106	0.00249025	-0.000209265	-0	-4.89625E-05	1.08248E-05	6.54779E-06	1.24721E-06	9.17885E-08	-4.75017E-08	0	**-0.027013**
27	0	8.0266E-106	0.002663332	-0.000738865	-0	1.39358E-05	-9.66807E-06	4.35556E-06	1.3208E-06	2.96118E-07	-6.07337E-08	0	**-0.087326**
28	0	7.5902E-106	0.001718641	-0.000899198	-0	6.73943E-05	-2.2676E-05	-1.65141E-06	9.74827E-08	1.77081E-07	-7.38823E-10	-0	**-0.125206**
29	0	7.0864E-106	5.26528E-05	-0.000610131	-0	7.52015E-05	-1.81285E-05	-6.21202E-06	-1.22156E-06	-1.35332E-07	6.01468E-08	-0	**-0.135976**
30	0	6.5197E-106	-0.001635433	-1.61342E-05	0	3.2069E-05	4.53831E-07	-5.33194E-06	-1.34113E-06	-2.9996E-07	4.85132E-08	0	**-0.11987**
31	0	5.8951E-106	-0.002637144	0.000585926	0	-3.27863E-05	1.86848E-05	2.18038E-07	-1.43823E-07	-1.37026E-07	-2.1613E-08	0	**-0.081925**
32	0	5.2182E-106	-0.002532072	0.000895153	0	-7.54329E-05	2.24503E-05	5.57705E-06	1.19471E-06	1.75543E-07	-6.56803E-08	-0	**-0.030997**
33	0	4.495E-106	-0.001364315	0.000757003	0	-6.69831E-05	8.83506E-06	6.05149E-06	1.36013E-06	2.96416E-07	-3.05566E-08	-0	**0.021933**

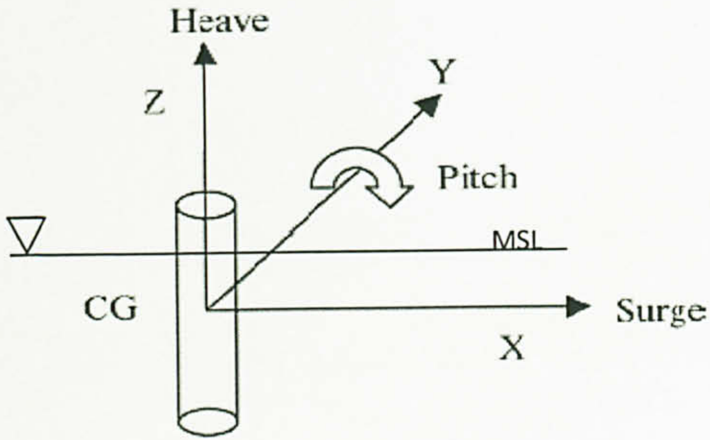
APPENDIX H

Pitch Motion Response

PITCH RESPONSE

Total Moment, Nm	421349708.7
ρ	1030
g	9.8067
D	46
added mass MI, kg-m^2	3.72E+10
struct. Mass MI, kg-m^2	3.72E+10
total MI, kg-m^2	7.44E+10
ωn	0.104719755
K, N.m/radian	8.16E+08
Cc	1.56E+10
C	7.79E+08
ω	0.376238641
(k-mw^2)^2	9.43738E+19
(cw^2)	3.43622E+19
upper	35112475.73
lower	11346187729
RAO	0.00309465

CG Location from MSL = 65 m



PICTH MOTION RESPONSE

Total Moment, Nm	9244283589
ρ	1030
g	9.8067
D	46
added mass MI, kg-m^2	3.72E+10
struct. Mass MI, kg-m^2	3.72E+10
total MI, kg-m^2	7.44E+10
ωn	0.104719755
K, N.m/radian	8.16E+08
Cc	1.56E+10
C	7.79E+08
ω	0.376238641
(k-mw^2)^2	9.43738E+19
(cw^2)	3.43622E+19
upper	770356965.7
lower	11346187729
RAO	0.067895665

f, sp	H(f), sp	ω, Sp	Mz,N.m	S(f), m-s2	RAO pitch	Sz(f), m-s2	S(mx)*Δf), m2	Hf pitch, m	Rd	ξ(n)	ω(N), rad/s	T, s
0.005	0	0.031416	0	0	0.000	0	0	0	0.426953	2.682626	0.031415927	200
0.015	1.81011E-52	0.094248	0	4.0956E-103	0.000	0	0	0	0.223272	1.402859	0.09424778	66.66667
0.025	6.22799E-06	0.15708	0	4.84848E-10	0.000	0	0	0	0.608123	3.820949	0.157079633	40
0.035	0.41263124	0.219911	331497.075	2.128306758	0.000	7.26698E-09	7.26698E-11	2.41114E-05	0.7113	4.469227	0.219911486	28.57143
0.045	3.162122638	0.282743	12594387.2	124.9877447	0.002	0.000616001	6.16001E-06	0.007019978	0.882615	5.545634	0.282743339	22.22222
0.055	4.474265132	0.345575	25047698.6	250.2381059	0.004	0.004878083	4.87808E-05	0.019754661	0.79302	4.982693	0.345575192	18.18182
0.065	4.123129731	0.408407	25092587.6	212.5024848	0.004	0.004157335	4.15733E-05	0.018236961	0.231136	1.45227	0.408407045	15.38462
0.075	3.363027824	0.471239	20685189	141.3744518	0.004	0.001879533	1.87953E-05	0.012262245	0.828305	5.204396	0.471238898	13.33333
0.085	2.660303342	0.534071	16192921.8	88.46517338	0.003	0.000720747	7.20747E-06	0.007593402	0.399698	2.511379	0.534070751	11.76471
0.095	2.103837163	0.596903	14040071.3	55.32663513	0.002	0.00033887	3.3887E-06	0.005206687	0.130364	0.819098	0.596902604	10.52632
0.105	1.680512164	0.659734	9092935.95	35.30151419	0.002	9.06905E-05	9.06905E-07	0.002693555	0.69017	4.336466	0.659734457	9.52381
0.115	1.360015065	0.722566	6824470.06	23.12051221	0.001	3.34576E-05	3.34576E-07	0.001636035	0.924791	5.810631	0.72256631	8.695652
0.125	1.115461559	0.785398	5270582.47	15.55318112	0.001	1.34245E-05	1.34245E-07	0.001036319	0.579499	3.641102	0.785398163	8
0.135	0.92654788	0.84823	4076364.59	10.73113718	0.001	5.54054E-06	5.54054E-08	0.000665765	0.185235	1.163867	0.848230016	7.407407
0.145	0.778632258	0.911062	3174752.9	7.578352418	0.001	2.37331E-06	2.37331E-08	0.000435735	0.379763	2.386124	0.91106187	6.896552
0.155	0.661262569	0.973894	2488118.11	5.465852308	0.000	1.05138E-06	1.05138E-08	0.000290018	0.250666	1.574984	0.973893723	6.451613
0.165	0.566948059	1.036726	2011157.05	4.017876266	0.000	5.0495E-07	5.0495E-09	0.000200988	0.387815	2.436716	1.036725576	6.060606
0.175	0.490267353	1.099557	1596481.07	3.004525963	0.000	2.37938E-07	2.37938E-09	0.000137967	0.410987	2.582305	1.099557429	5.714286
0.185	0.427248773	1.162389	1310347.25	2.281768926	0.000	1.21732E-07	1.21732E-09	9.86841E-05	0.312492	1.963445	1.162389282	5.405405
0.195	0.374945043	1.225221	1083129.64	1.757297317	0.000	6.40569E-08	6.40569E-10	7.1586E-05	0.245401	1.541899	1.225221135	5.128205
0.205	0.331140984	1.288053	859265.602	1.370679389	0.000	3.14449E-08	3.14449E-10	5.01557E-05	0.096707	0.607627	1.288052988	4.878049
0.215	0.294151086	1.350885	694227.904	1.081560764	0.000	1.61963E-08	1.61963E-10	3.59959E-05	0.216898	1.362808	1.350884841	4.651163
0.225	0.262677845	1.413717	580957.041	0.862495629	0.000	9.04493E-09	9.04493E-11	2.68997E-05	0.512827	3.22219	1.413716694	4.444444
0.235	0.235711464	1.476549	513134.946	0.694498681	0.000	5.68191E-09	5.68191E-11	2.13203E-05	0.564225	3.545127	1.476548547	4.255319
0.245	0.212457977	1.53938	405686.55	0.564229897	0.000	2.88534E-09	2.88534E-11	1.5193E-05	0.463917	2.914874	1.5393804	4.081633

Hf pitch, m	0	0	0.005206687	0.002693555	0.000290018	0.000200988	0.000137967	9.86841E-05	7.1586E-05	2.13203E-05	0	
f, (n)	0.01	0.015	0.095	0.105	0.155	0.165	0.175	0.185	0.195	0.235	0.25	
ξ(n)	2.68	1.402858997	0.819098362	4.336465605	1.574983751	2.436716148	2.582304656	1.963445011	1.541898833	3.54512712	2.91	
t	η= (H(n)/2)*COS(-2*PI()*f(n)*t+ξ(n))											sum
1	0	0	0.002539343	-0.001158495	0.000119592	1.70816E-05	6.06611E-06	3.43396E-05	3.40132E-05	-5.08998E-06	0	0.006062503
2	0	0	0.00242271	-0.001336337	0.000135048	9.39357E-05	6.39808E-05	4.61559E-05	2.20089E-05	8.84587E-06	0	0.003453223
3	0	0	0.001468211	-0.000953332	3.2225E-05	7.85528E-05	5.20273E-05	2.32185E-06	-1.91027E-05	6.75492E-06	-0	-0.000250602
4	0	0	5.94674E-06	-0.000170223	-9.8822E-05	-1.39625E-05	-1.67411E-05	-4.43116E-05	-3.49505E-05	-7.57449E-06	-0	-0.004322783
5	0	0	-0.001458374	0.000684327	-0.000143317	-9.27678E-05	-6.72278E-05	-3.75184E-05	-4.57547E-06	-8.18056E-06	0	-0.00783418
6	0	0	-0.002418332	0.001251672	-6.22907E-05	-8.04828E-05	-4.43005E-05	1.45109E-05	3.18508E-05	6.03477E-06	0	-0.010234976
7	0	0	-0.002541937	0.001293702	7.32923E-05	1.08296E-05	2.70038E-05	4.90444E-05	2.61536E-05	9.31641E-06	-0	-0.011458475
8	0	0	-0.001786442	0.000792779	0.000144683	9.15082E-05	6.88195E-05	2.44448E-05	-1.41323E-05	-4.28127E-06	-0	-0.011600627
9	0	0	-0.000413125	-4.0866E-05	8.93561E-05	8.23333E-05	3.5483E-05	-2.9628E-05	-3.57279E-05	-1.01222E-05	-0	-0.010659659
10	0	0	0.001103066	-0.00085736	-4.42324E-05	-7.68609E-06	-3.66016E-05	-4.79782E-05	-1.00725E-05	2.3761E-06	0	-0.008549009
11	0	0	0.002237774	-0.001314028	-0.000139081	-9.01584E-05	-6.87165E-05	-8.48089E-06	2.89041E-05	1.05694E-05	0	-0.00522484
12	0	0	0.002598573	-0.001219212	-0.000112117	-8.41026E-05	-2.57917E-05	4.12418E-05	2.96543E-05	-3.86755E-07	-0	-0.000821978
13	0	0	0.002060684	-0.000612705	1.30419E-05	4.53496E-06	4.52981E-05	4.12391E-05	-8.81402E-06	-1.06422E-05	-0	0.004169446
14	0	0	0.000810131	0.000250948	0.000126779	8.87196E-05	6.69216E-05	-8.48579E-06	-3.56256E-05	-1.61629E-06	0	0.008821349
15	0	0	-0.000720597	0.001009281	0.000129479	8.57889E-05	1.54654E-05	-4.79793E-05	-1.53214E-05	1.0338E-05	0	0.012038767
16	0	0	-0.002002115	0.001344029	1.87767E-05	-1.37935E-06	-5.28793E-05	-2.9624E-05	2.52457E-05	3.56207E-06	-0	0.013112603
17	0	0	-0.002591223	0.001114701	-0.00010837	-8.71932E-05	-6.34788E-05	2.44491E-05	3.24248E-05	-9.66757E-06	-0	0.012078085
18	0	0	-0.002284186	0.000417545	-0.000140603	-8.73906E-05	-4.7582E-06	4.90438E-05	-3.27867E-06	-5.38167E-06	0	0.009559067
19	0	0	-0.001187189	-0.000454851	-4.96909E-05	-1.77762E-06	5.91584E-05	1.45062E-05	-3.4646E-05	8.65465E-06	0	0.006323689
20	0	0	0.000320385	-0.001136351	8.47422E-05	8.55808E-05	5.84729E-05	-3.75216E-05	-2.01931E-05	7.01062E-06	-0	0.002978986
21	0	0	0.001717157	-0.001340935	0.000144955	8.8906E-05	-6.06611E-06	-4.43094E-05	2.09656E-05	-7.33514E-06	-0	-8.73007E-05
22	0	0	0.002520069	-0.000982742	7.82117E-05	4.93284E-06	-6.39808E-05	2.32681E-06	3.43968E-05	-8.39122E-06	0	-0.002698413
23	0	0	0.002451444	-0.000212103	-5.70322E-05	-8.3884E-05	-5.20273E-05	4.61576E-05	2.33742E-06	5.75577E-06	0	-0.004894412
24	0	0	0.001535014	0.000647554	-0.000142325	-9.03337E-05	1.67411E-05	3.4336E-05	-3.28133E-05	9.47455E-06	-0	-0.006842724
25	0	0	8.77166E-05	0.001235439	-0.000102965	-8.08319E-06	6.72278E-05	-1.88847E-05	-2.45676E-05	-3.9725E-06	-0	-0.008620905
26	0	0	-0.001389917	0.001304823	2.65753E-05	8.21043E-05	4.43005E-05	-4.9336E-05	1.61693E-05	-1.02222E-05	0	-0.010042014
27	0	0	-0.002386863	0.000826585	0.00013284	9.16722E-05	-2.70038E-05	-2.03027E-05	3.55219E-05	2.04851E-06	0	-0.010687108
28	0	0	-0.002558339	1.43801E-06	0.000122759	1.12256E-05	-6.88195E-05	3.32097E-05	7.89595E-06	1.06078E-05	-0	-0.010101951
29	0	0	-0.001845042	-0.000824313	5.16172E-06	-8.02436E-05	-3.5483E-05	4.6681E-05	-3.01726E-05	-5.19421E-08	-0	-0.007992984
30	0	0	-0.000493658	-0.001304108	-0.000116957	-9.29202E-05	3.66016E-05	3.86885E-06	-2.83372E-05	-1.06176E-05	0	-0.004342472
31	0	0	0.001028452	-0.001236582	-0.000136641	-1.43568E-05	6.87165E-05	-4.3608E-05	1.09749E-05	-1.94646E-06	0	0.000521097
32	0	0	0.002194883	-0.000650075	-3.66501E-05	7.83037E-05	2.57917E-05	-3.85065E-05	3.57724E-05	1.02512E-05	-0	0.005889304
33	0	0	0.002602239	0.000209262	9.54399E-05	9.40765E-05	-4.52981E-05	1.30224E-05	1.32601E-05	3.87591E-06	-0	0.010763175
34	0	0	0.002109639	0.000980774	0.00014394	1.7474E-05	-6.69216E-05	4.88502E-05	-2.6789E-05	-9.52171E-06	0	0.014114684
35	0	0	0.000887444	0.001340664	6.63732E-05	-7.62866E-05	-1.54654E-05	2.5779E-05	-3.1409E-05	-5.66806E-06	0	0.015199652
36	0	0	-0.000641664	0.001137892	-6.93259E-05	-9.514E-05	5.28793E-05	-2.8374E-05	5.51021E-06	8.45489E-06	-0	0.013732323
37	0	0	-0.001948859	0.000457557	-0.000144307	-2.05739E-05	6.34788E-05	-4.83164E-05	3.5142E-05	7.25941E-06	-0	0.009887514
38	0	0	-0.002582063	-0.000414809	-9.28993E-05	7.41942E-05	4.7582E-06	-1.00035E-05	1.82977E-05	-7.08855E-06	0	0.00426136
39	0	0	-0.00232229	-0.001113085	3.98728E-05	9.61097E-05	-5.91584E-05	4.03706E-05	-2.27458E-05	-8.59359E-06	0	-0.002156545
40	0	0	-0.001259378	-0.001344209	0.000137723	2.36534E-05	-5.84729E-05	4.20697E-05	-3.37074E-05	5.47109E-06	-0	-0.008136884
41	0	0	0.000239075	-0.001011183	0.000114951	-7.20285E-05	6.06611E-06	-6.95482E-06	-9.01422E-08	9.62334E-06	-0	-0.012578979

APPENDIX I

Motion Responses Data from Experiment

WAVE PROFILE FOR 60 SECONDS

Time (s)	Surge	Heave	Pitch	Pitch (rad)
0	0	0	0	0
1	-0.7	-1	0.5	0.00833
2	2	-0.75	0.2	0.00333
3	0.5	0.5	0.3	0.005
4	0.3	1.5	0.1	0.00167
5	-1.5	-1	-0.2	-0.00333
6	2	-2.4	0.8	0.0133
7	2.5	0.1	0.4	0.00667
8	1	0	-0.3	-0.005
9	-2	-0.1	0	0
10	-1	0	0	0
11	0.5	-0.2	0.1	0.001667
12	1.3	-0.5	0.2	0.00333
13	0	-0.45	-0.2	-0.00333
14	-0.5	-0.2	-0.1	-0.00167
15	-0.3	-0.1	0	0
16	-0.1	0	-1.5	-0.025
17	0.8	-0.7	0.2	0.00333
18	0.25	1.5	0	0
19	0.3	0.3	0.4	0.00667
20	0.1	2.5	0.8	0.0133
21	-1.5	0	0	0
22	1	-0.4	0.2	0.0033
23	-0.8	0	-0.8	-0.01333
24	0	0	0.1	0.001667
25	1.75	0.1	0.5	0.00833
26	2.23	-0.3	0.7	0.011667
27	1	-0.2	-0.4	-0.00667
28	-2	0	0	0
29	1.8	-0.1	0.1	0.001667
30	2	0	1.3	0.021667

Time (s)	Surge	Heave	Pitch	Pitch (rad)
31	1.7	0.25	0.1	0.001667
32	-0.5	-0.3	0.5	0.008333
33	0.8	0	0.2	0.00333
34	-0.9	0.1	0	0
35	0	-0.13	-0.1	-0.00167
36	0.6	-0.5	-0.3	-0.005
37	1	-0.8	0.2	0.00333
38	0.3	0.4	0.5	0.008333
39	1.2	1.5	-0.2	-0.00333
40	1.8	-0.8	1.8	0.03
41	-0.3	0.2	0.3	0.005
42	0.8	0.1	0.1	0.001667
43	1.2	-0.8	-0.1	-0.00167
44	-2.5	0	0.4	0.006667
45	2.3	-0.2	0.2	0.00333
46	3.2	0.5	0	0
47	2.5	0	0.1	0.001667
48	-0.3	2	0	0
49	1.3	0.2	0.3	0.005
50	1.5	1.5	0.1	0.001667
51	1.8	0.8	0.4	0.00667
52	0.9	0.3	0.2	0.00333
53	0	-2.5	-0.2	-0.00333
54	-0.5	0.1	-1	-0.01667
55	0	0.5	0.1	0.001667
56	1	-0.2	0.2	0.00333
57	0	0	0.1	0.001667
58	0.2	0.4	0.05	0.000833
59	-1	0.2	0	0
60	1.5	-0.2	0.5	0.008333